Measurements of Photocathode Operational Lifetime at Beam Currents up to 10 mA using an Improved DC High Voltage GaAs Photogun

J. Grames, M. Poelker, P. Adderley, J. Brittian, J. Clark,
J. Hansknecht, M. Stutzman, K. Surles-Law

BNL C-A Department
February 9, 2007

Purpose & Overview

Goal: Deliver high average current (> 1mA) and high polarization (> 80%) with long photocathode operational lifetime in support of new accelerator initiatives.

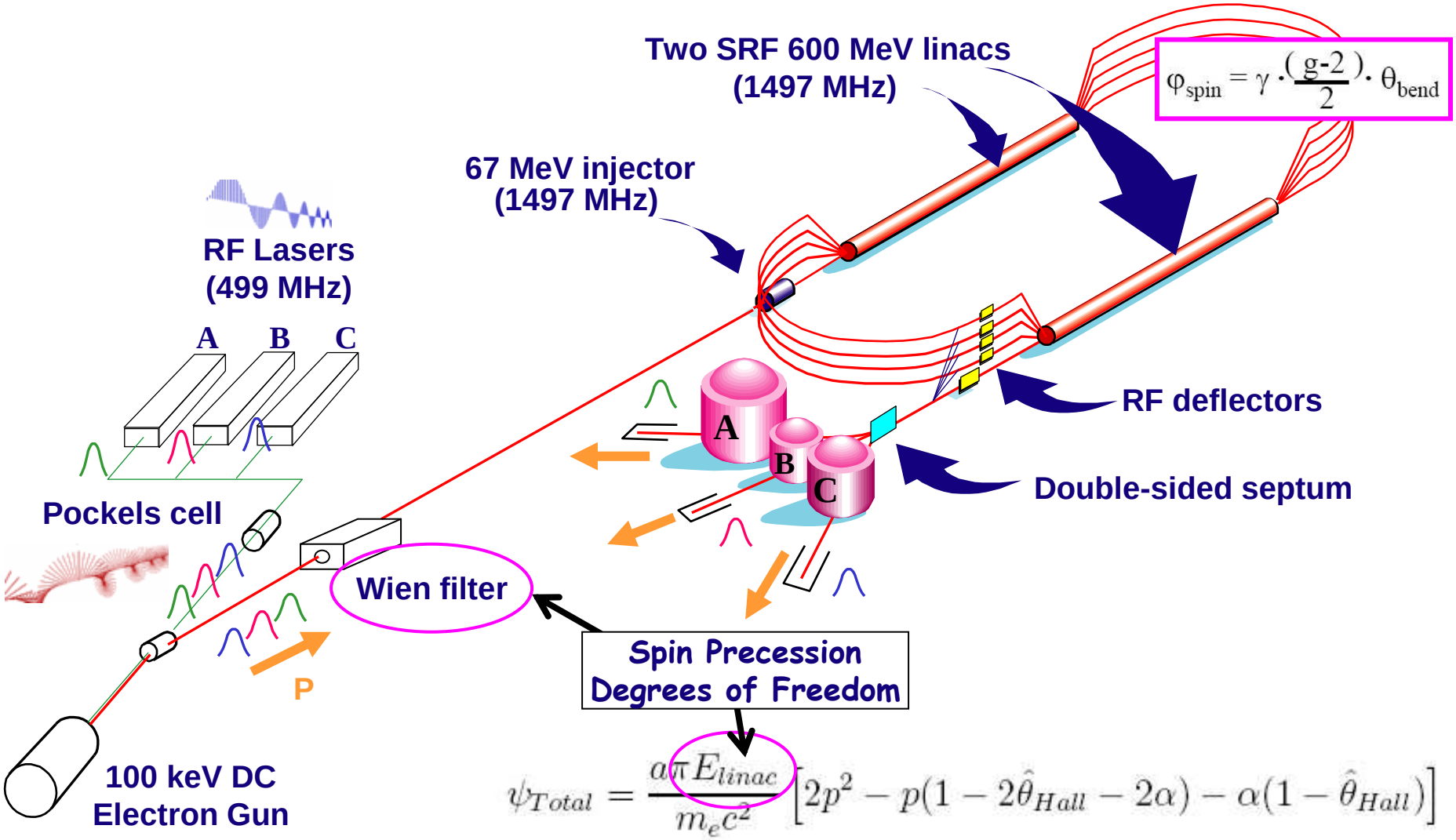
Enhance our understanding of photocathode decay mechanism. This will undoubtedly allow us to improve existing polarized guns operating at lower average current and unpolarized guns at milliAmp beam currents (e.g., Lightsources).

- Background
- R&D Program
- New DC HV Load Lock Gun
- Low-P GaAs Studies
- High-P GaAs Studies

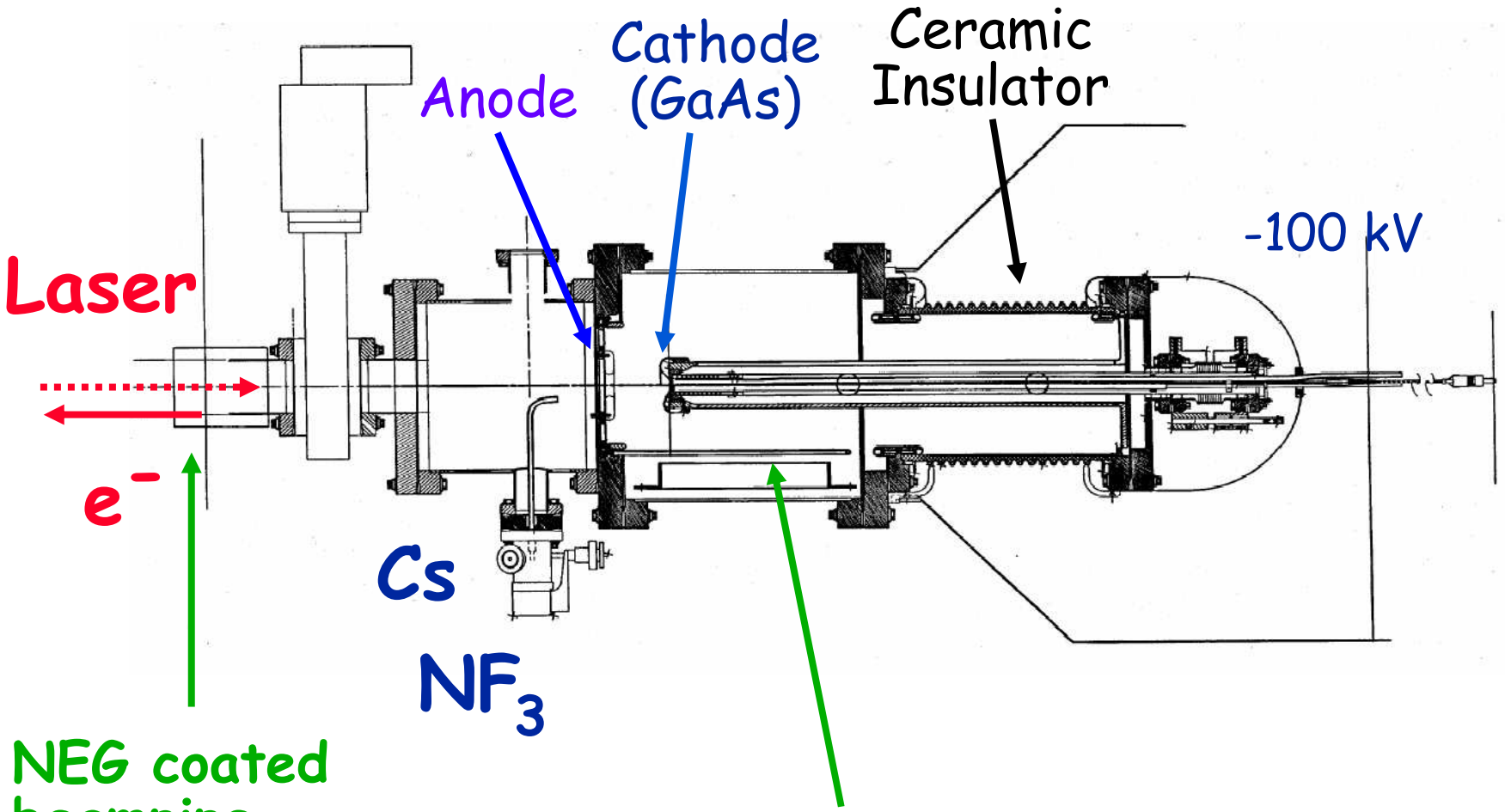
CEBAF Polarized e^- Source

- CEBAF's first polarized e-beam experiment 1997
- Now polarized beam experiments comprise ~ 80% of our physics program, in fact, we *only* deliver polarized electrons
- All beam originates via photoemission from a Gallium Arsenside crystal inside a 100 kV photogun
  - 35 weeks of beam delivery per year
  - 100 μA at 85% polarization is fairly routine
- Three experimental areas may *simultaneously* receive:
  - high polarization (~85%) => large asymmetry/ figure of merit
  - continuous wave (499 MHz) => high statistics/ low couting rates
  - independent intensity (50 pA to 200 μA) => target / acceptance
  - energy selection (multiples of linac energy) => flexibility

Continuous Electron Beam Accelerator Facility

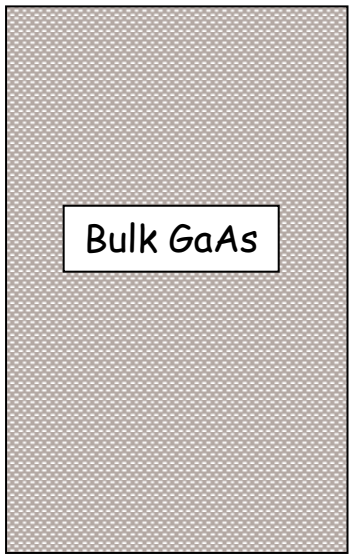


Present JLab "Vent/Bake" Polarized Electron Gun



GaAs Photocathodes

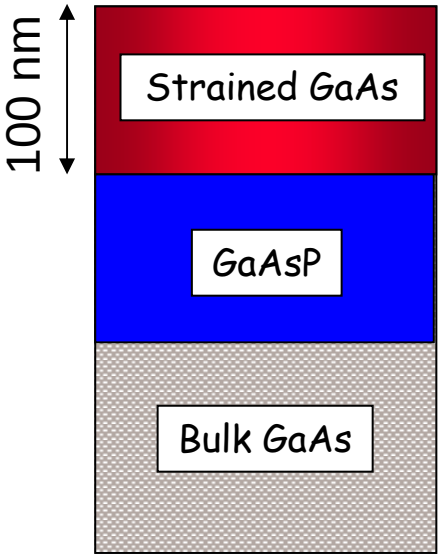
Unstrained GaAs



P ~ 35 - 40%

Degeneracy

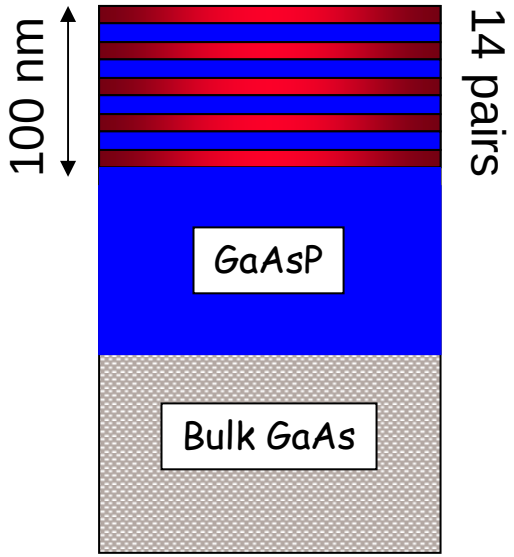
Strained GaAs



P ~ 70 – 75 %

Broken degeneracy,
but relaxation

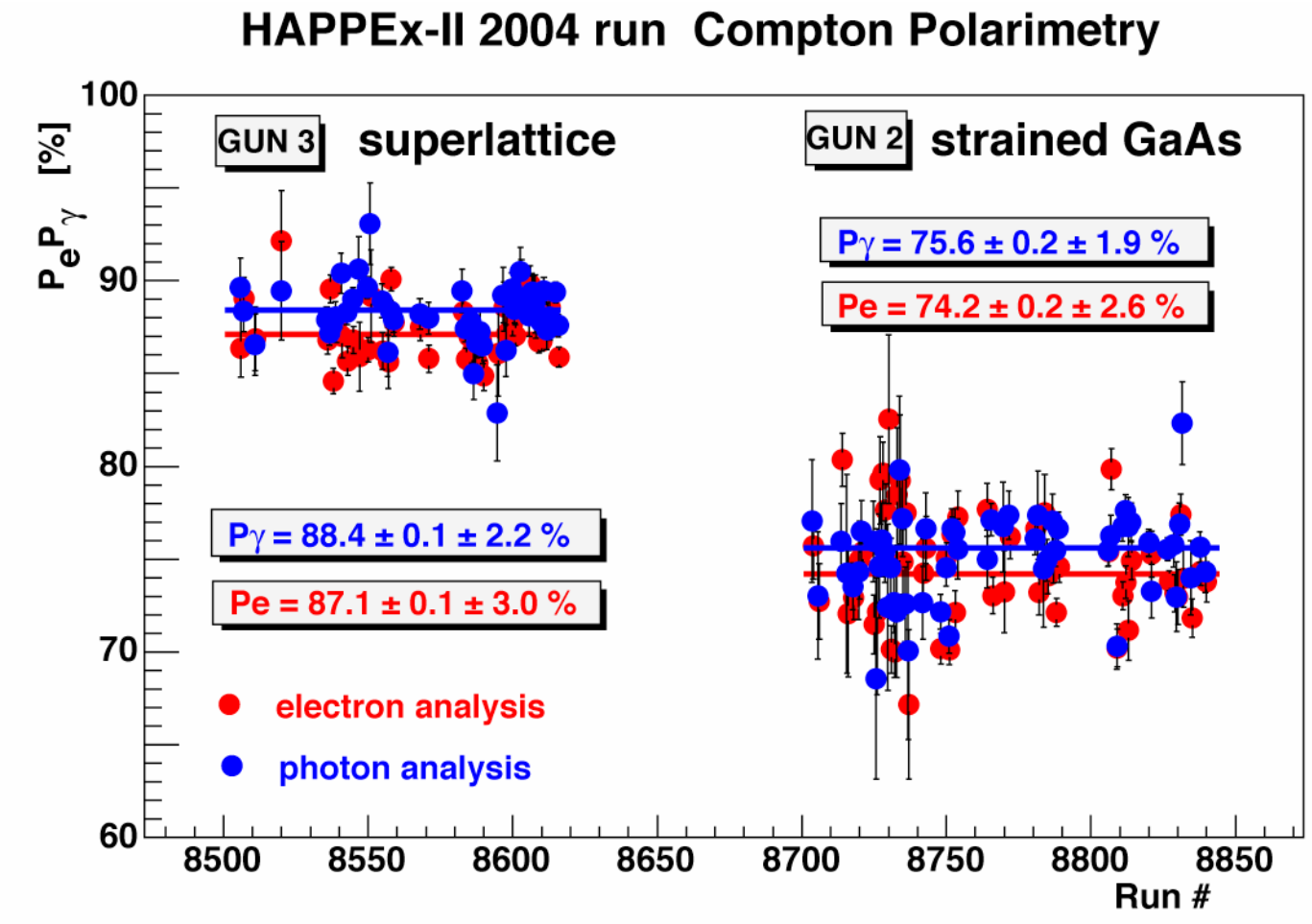
Superlattice GaAs



P ~ 80 - 90 %

No relaxation,
quantum well structure

Beam Polarization at CEBAF

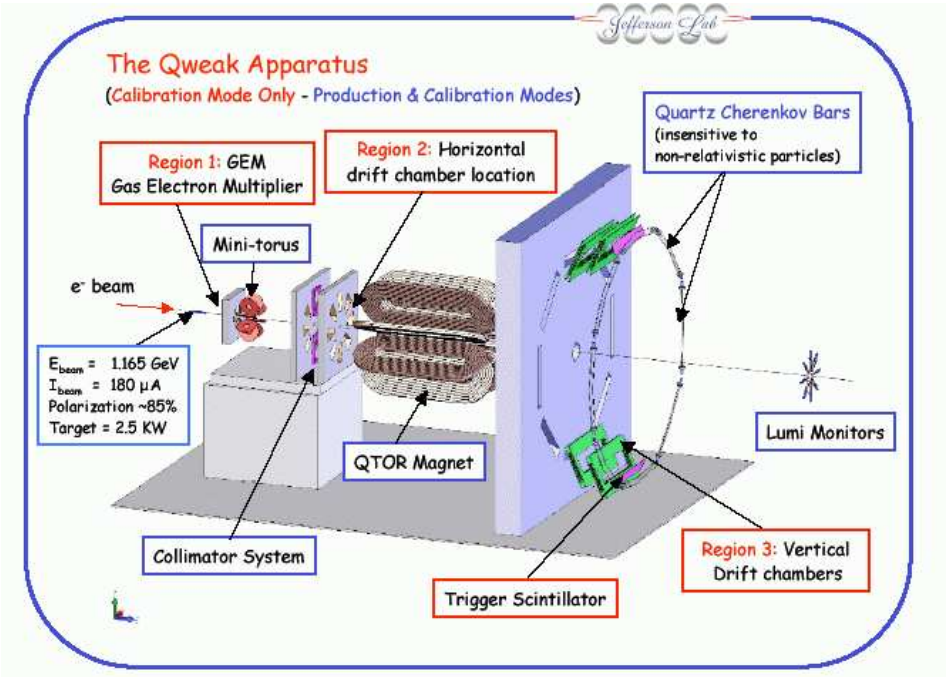


Experiment Figure of Merit

$$\frac{P_{sup.}^2 I}{P_{str.}^2 I} = 1.38$$

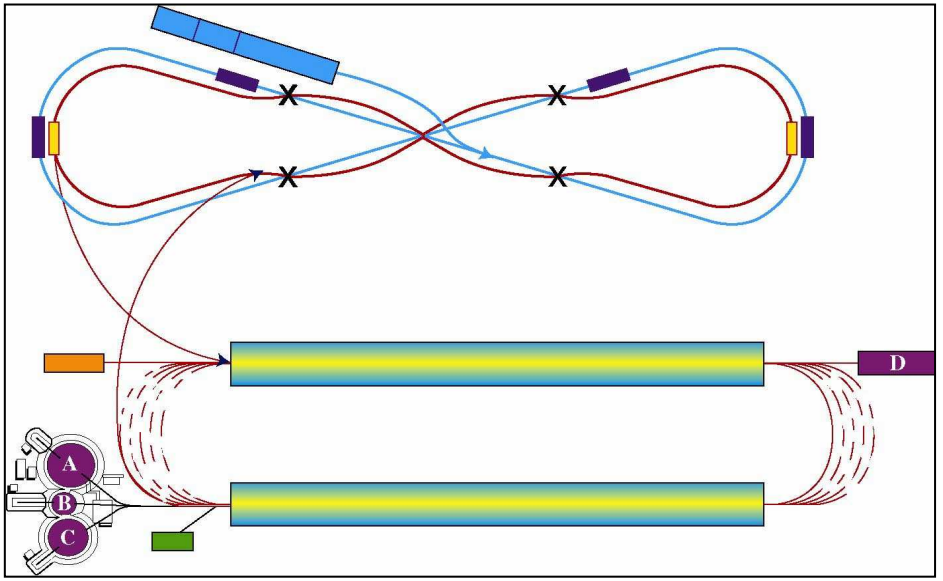
Future High Current/ High Polarization Projects

Q_{weak} to test standard model
>200 μA at 85% polarization



~20 C/day

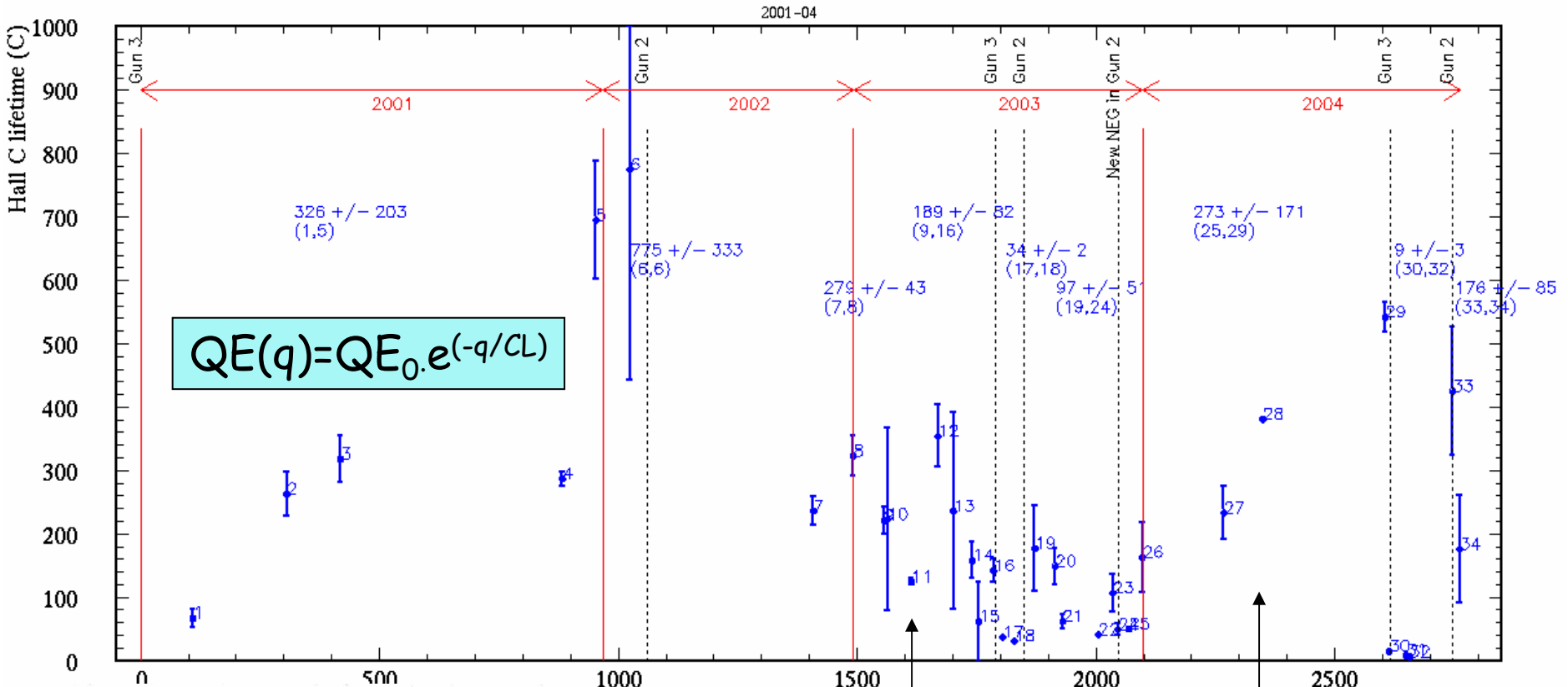
Proposed (>1 mA) facilities
ELIC, eRHIC

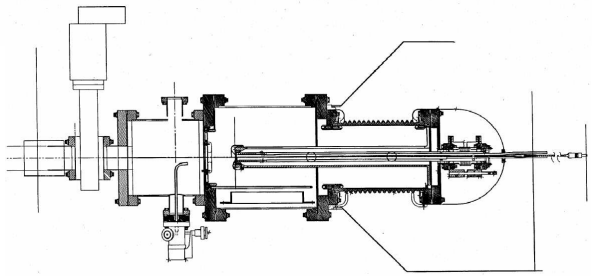


Ring <1 C/day
Linac >100 C/day

CEBAF Gun Charge Lifetime (2001-2004)

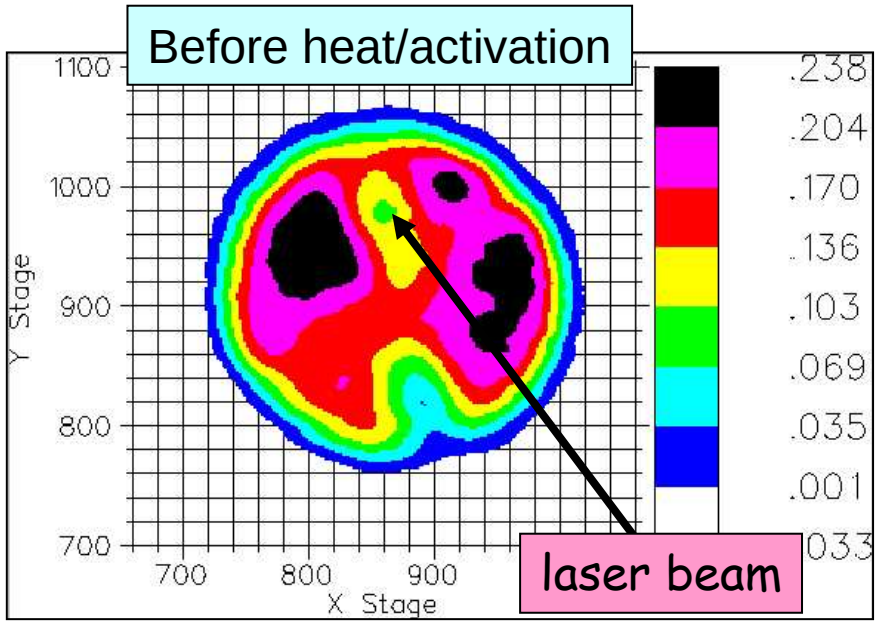
Data compiled by M. Baylac

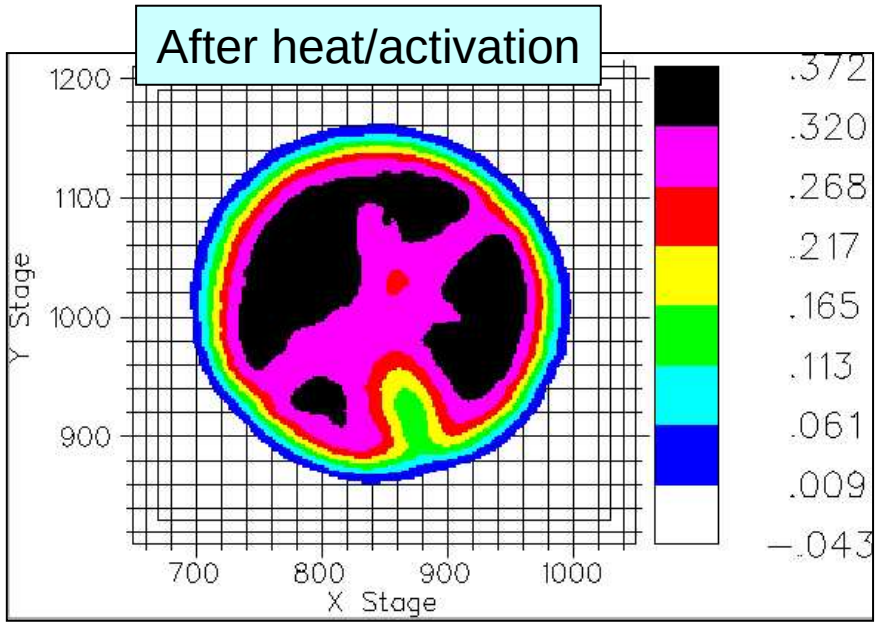




CEBAF Polarized Source

Photocathode “QE” Lifetime limited by ion back-bombardment.

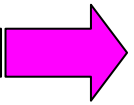




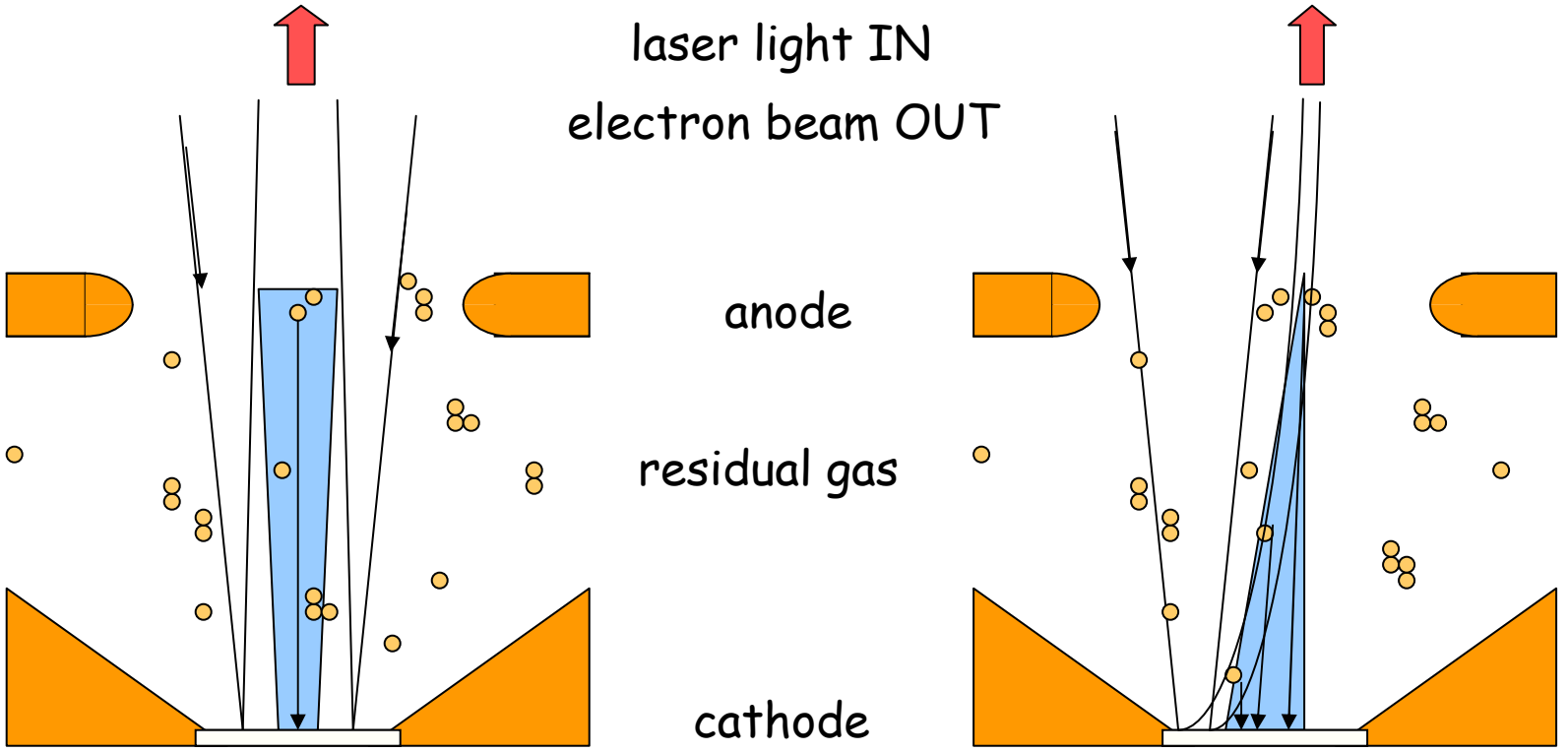
One photocathode operates for year(s), and multiple activations, usually limited by field emission from the cesiated electrode.

Ion Back-Bombardment

Ions accelerated & focused to electrostatic center



We don't run beam from electrostatic center

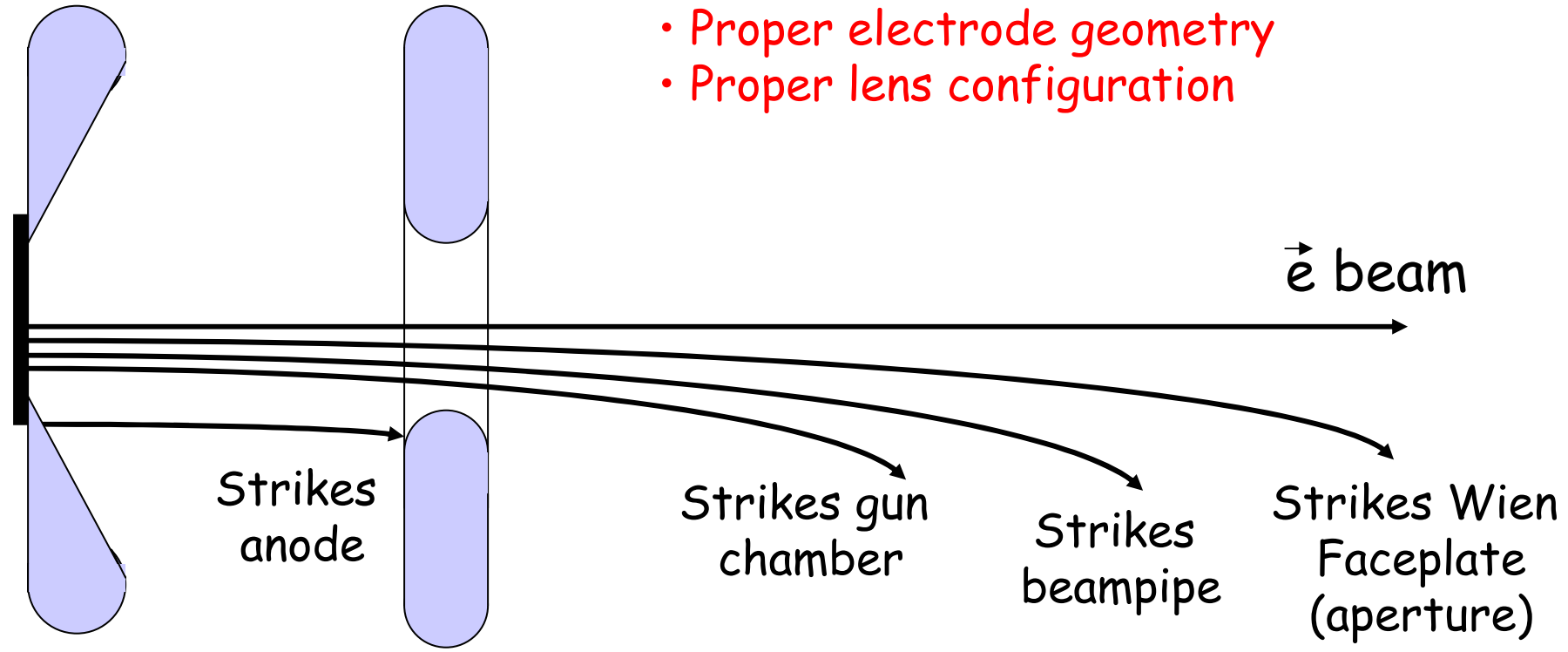


Which ions more problematic?

QE trough to electrostatic center

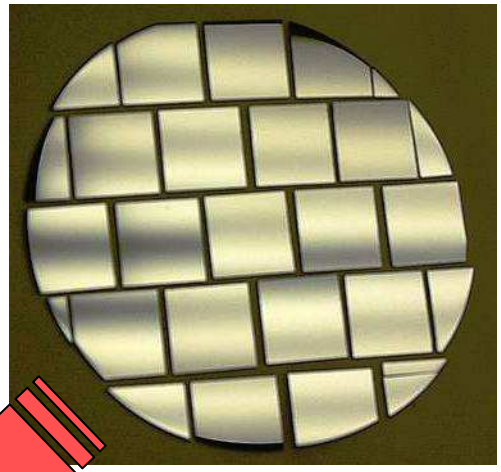
Experiment Requires Managing Electron Beam

- Limit photocathode active area
- Eliminate stray light
- Large diameter beampipes
- NEG coated chambers to limit ESD
- Proper electrode geometry
- Proper lens configuration



GaAs wafer…becomes a photocathode

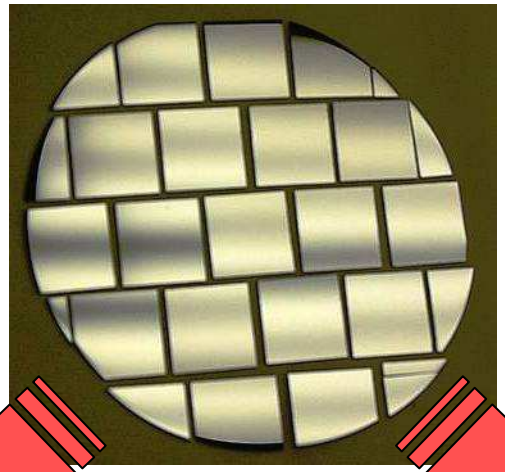
Wafer from vendor



Stalk Mounted

Paradigm Shift (Peggy Style => Load Lock Gun)

Wafer from vendor



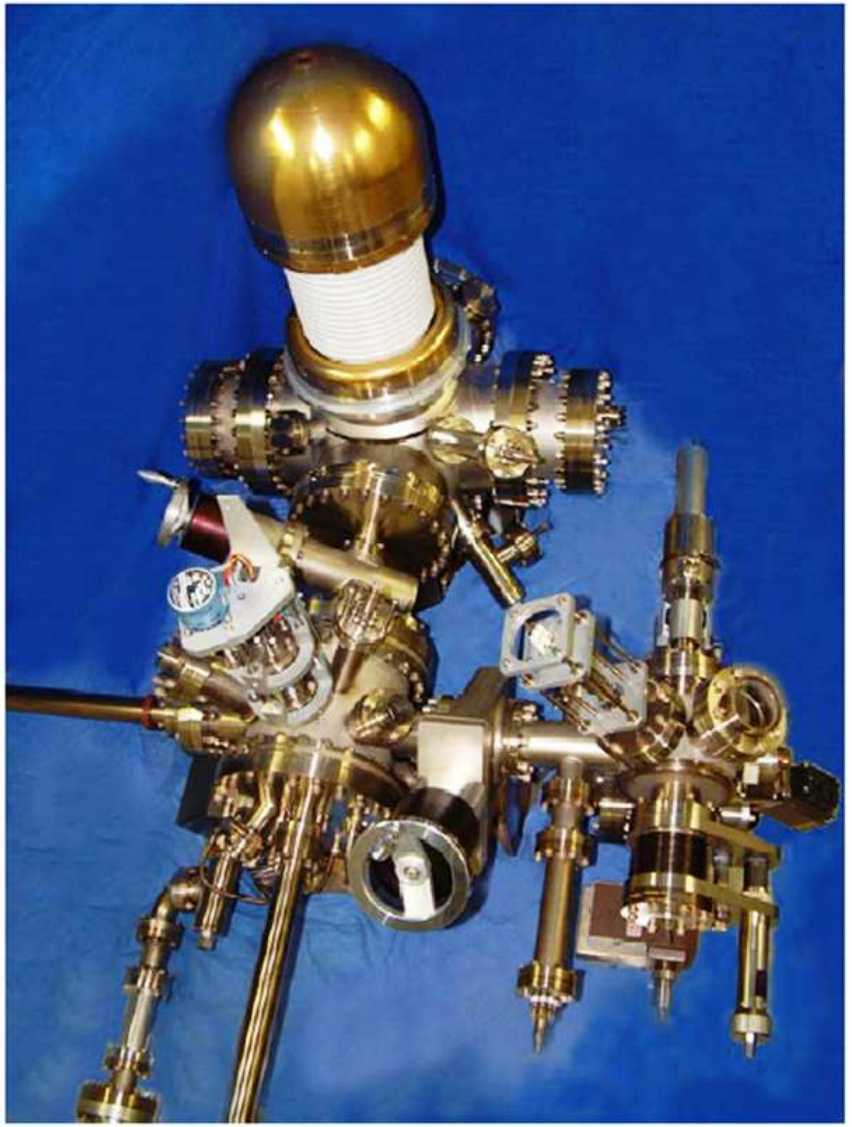
Stalk Mounted

Puck Mounted

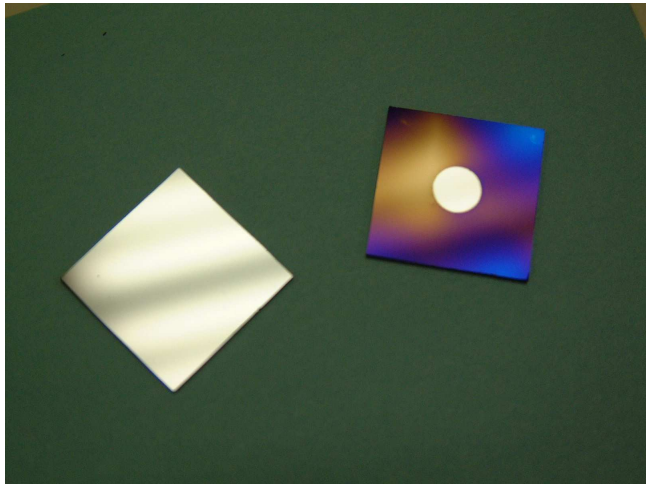
BTLLPEG Test Stand (2003-2006)

3 Chambers
- Load/Hydrogen/Heat
- Prepare NEA surface
- High Voltage, Good Vacuum

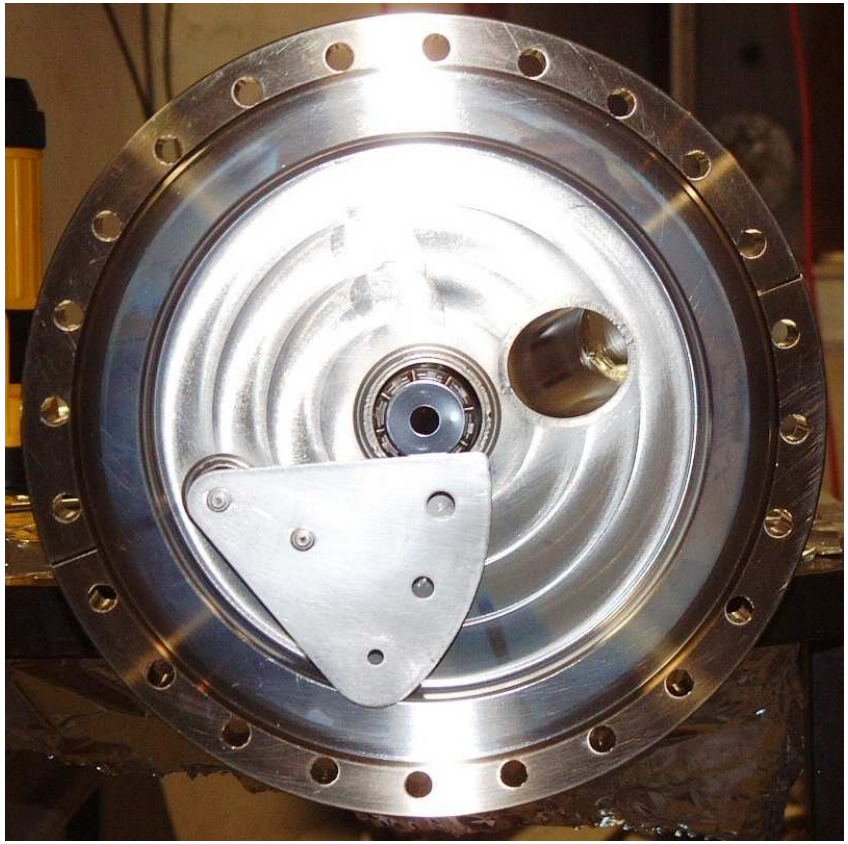
Photocathode Lifetime Test Bed
- Low-P bulk GaAs
- High QE (15-20%) => mA's
- 200 C/day vs. 10 C/day



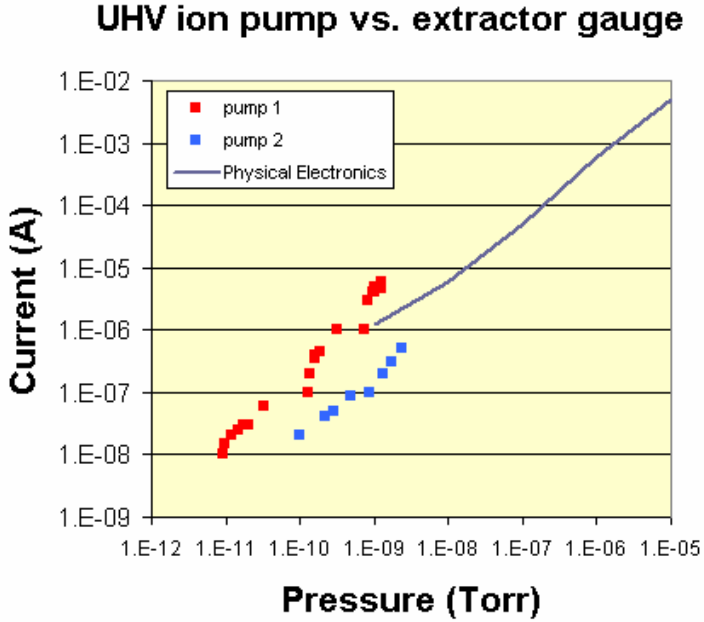
Improvements limiting the active area

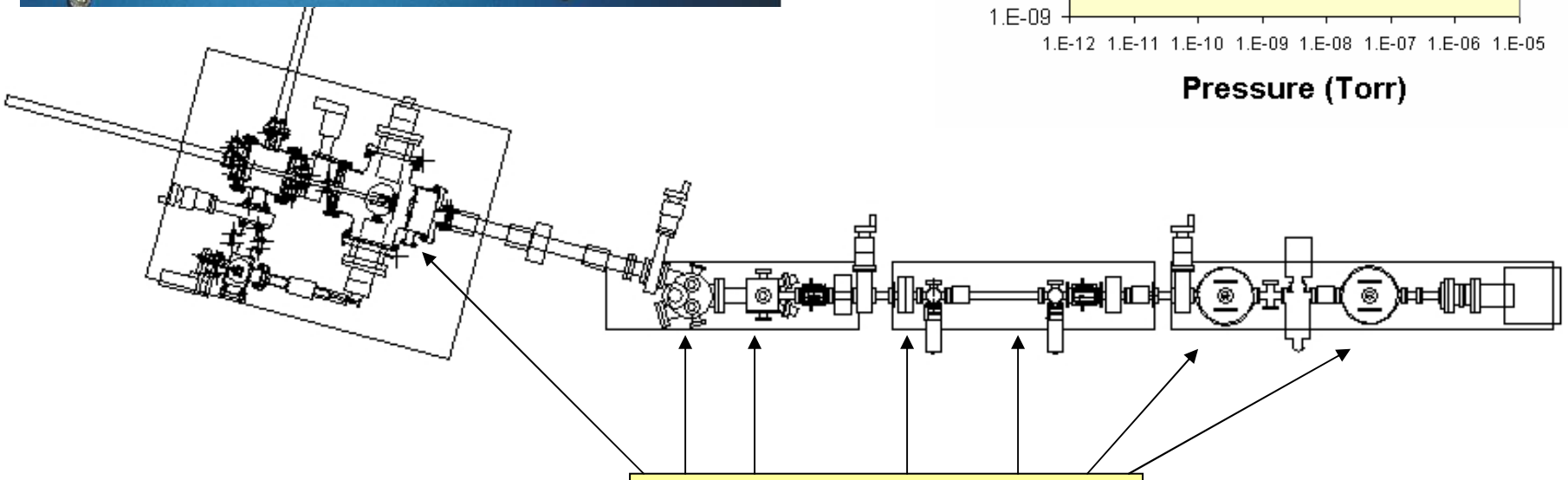


No more hydrogen cleaning
Study one sample without removal



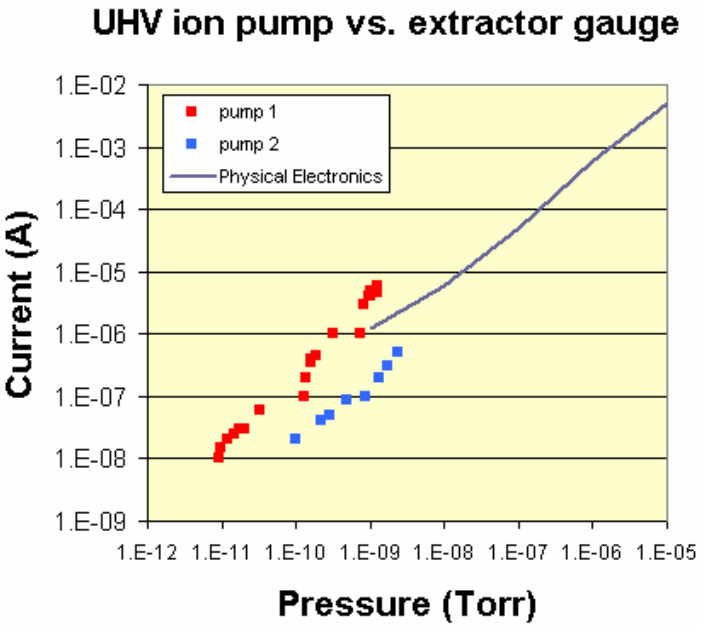
Improvements to monitor gun & beamline pressure

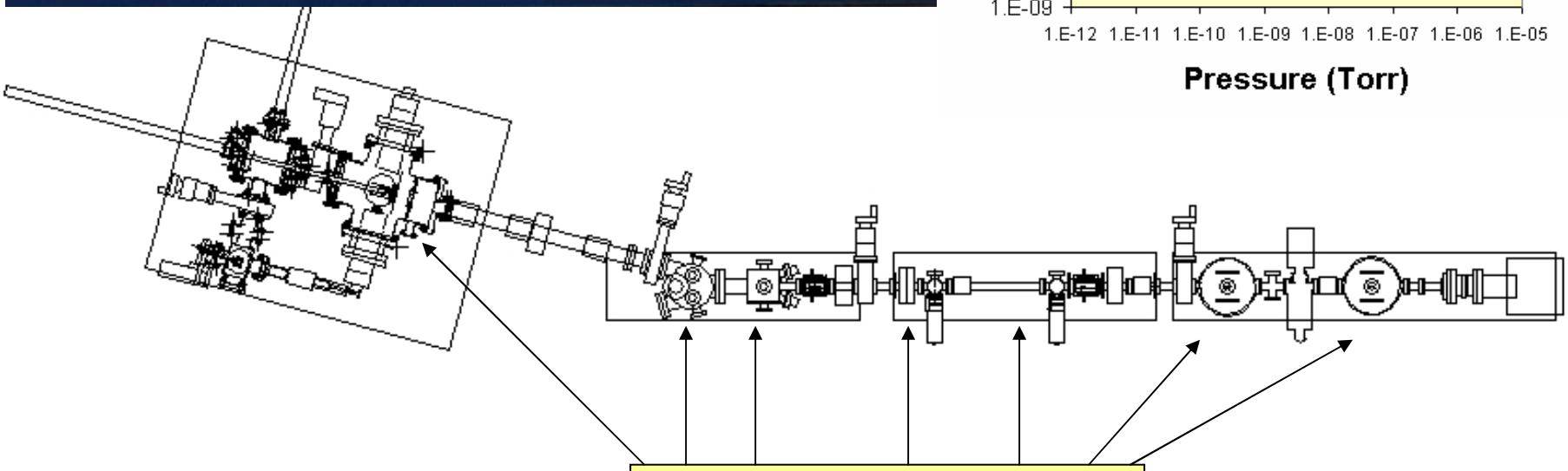




Ion Pump Locations

Improvements to monitor gun & beamline pressure





Ion Pump Locations

Photocathode Lifetime Studies & Operation (2003-2006)

We've learned about photocathode lifetime…

- vs. gun & beamline pressure (leaks, pumping, gauging)
- vs. laser (spot size, position, reflections, power levels)
- vs. GaAs preparation (active area, cleaning)
- vs. beam handling (optics, orbits, beam losses)

We've learned about functionality of a Load Lock gun…

- Round pucks + gravity = rolling
- Manipulator alignment + bake-outs
- Activation, heating, cooling
- Sensitivity of manipulators to bake temperature
- Multiple photocathodes > 1 photocathode

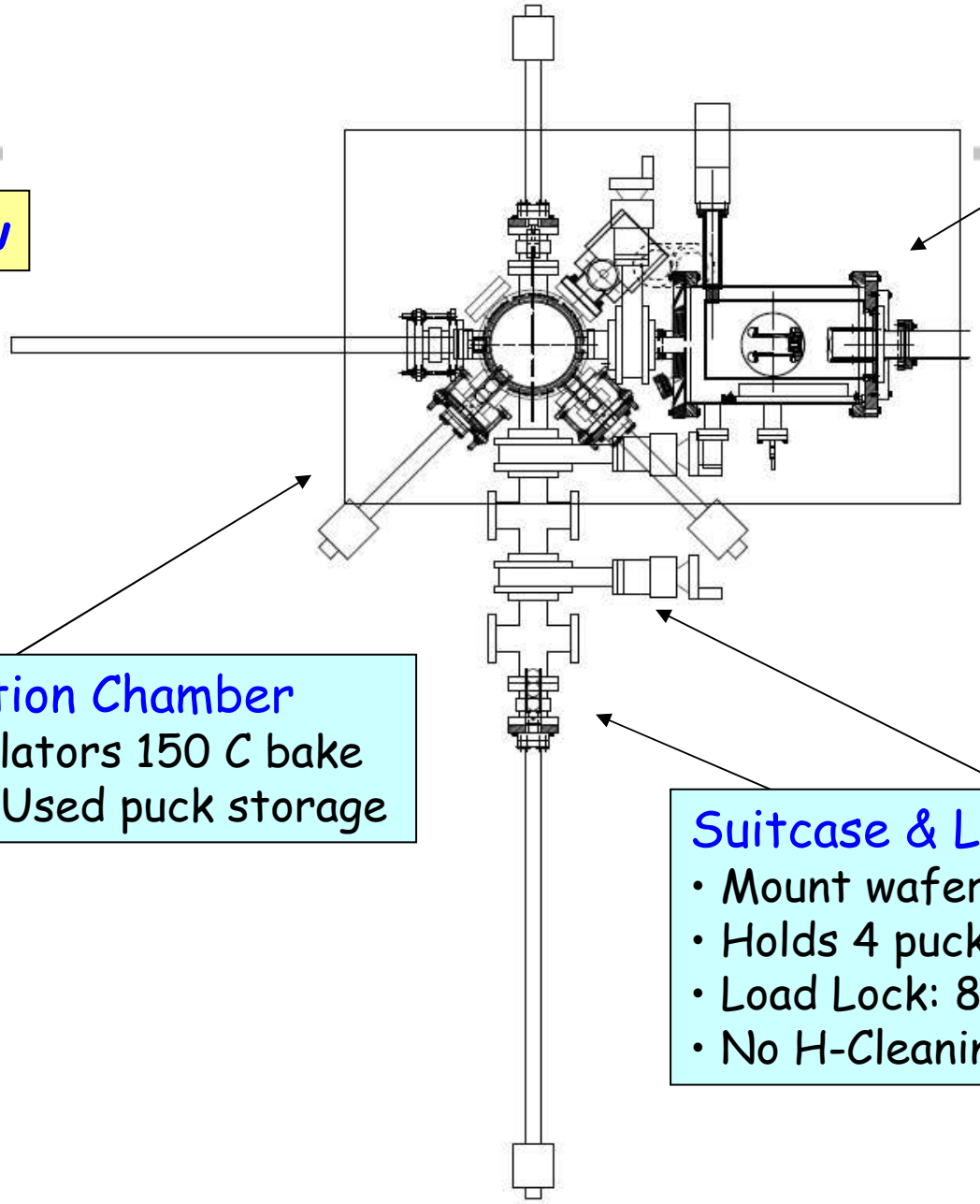
Work mainly presented at workshops & recorded in proceedings…

NEW Load Lock PhotoGun for CEBAF

What's next (really, now!)…

- Improve gun vacuum, photocathode lifetime
- Load multiple photocathodes with the "suitcase"
- Evolve the technology, i.e., design-out "features"
- Transfer the technology to the CEBAF program

Top View



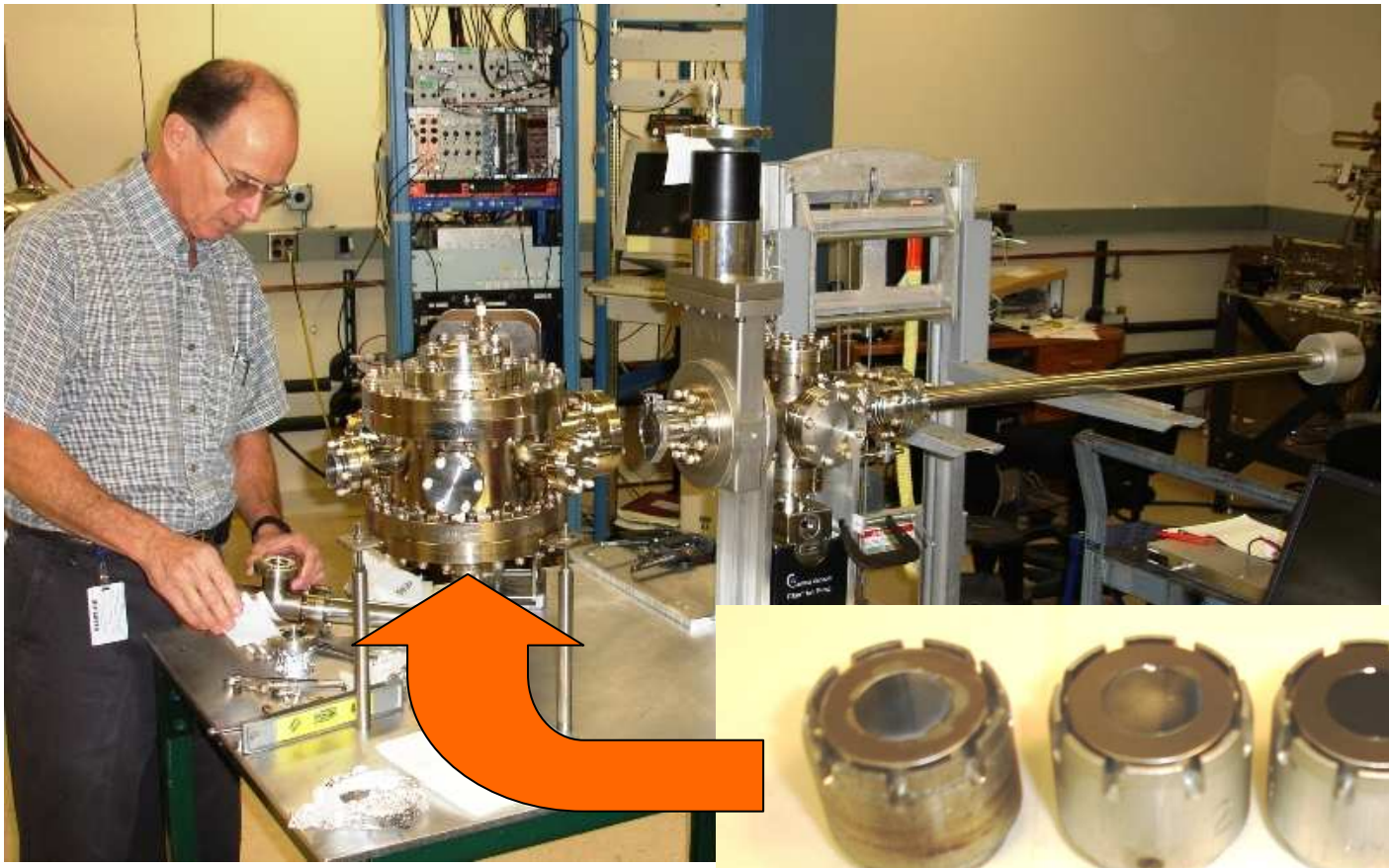
High Voltage Chamber

Beam

Activation Chamber
- Manipulators 150 C bake
- New & Used puck storage

Suitcase & Load Chamber
- Mount wafer on puck in lab
- Holds 4 pucks (e.g., bulk, SL, SSL)
- Load Lock: 8 hour bake @ 250 C
- No H-Cleaning

Docking Chamber & "Suitcase"



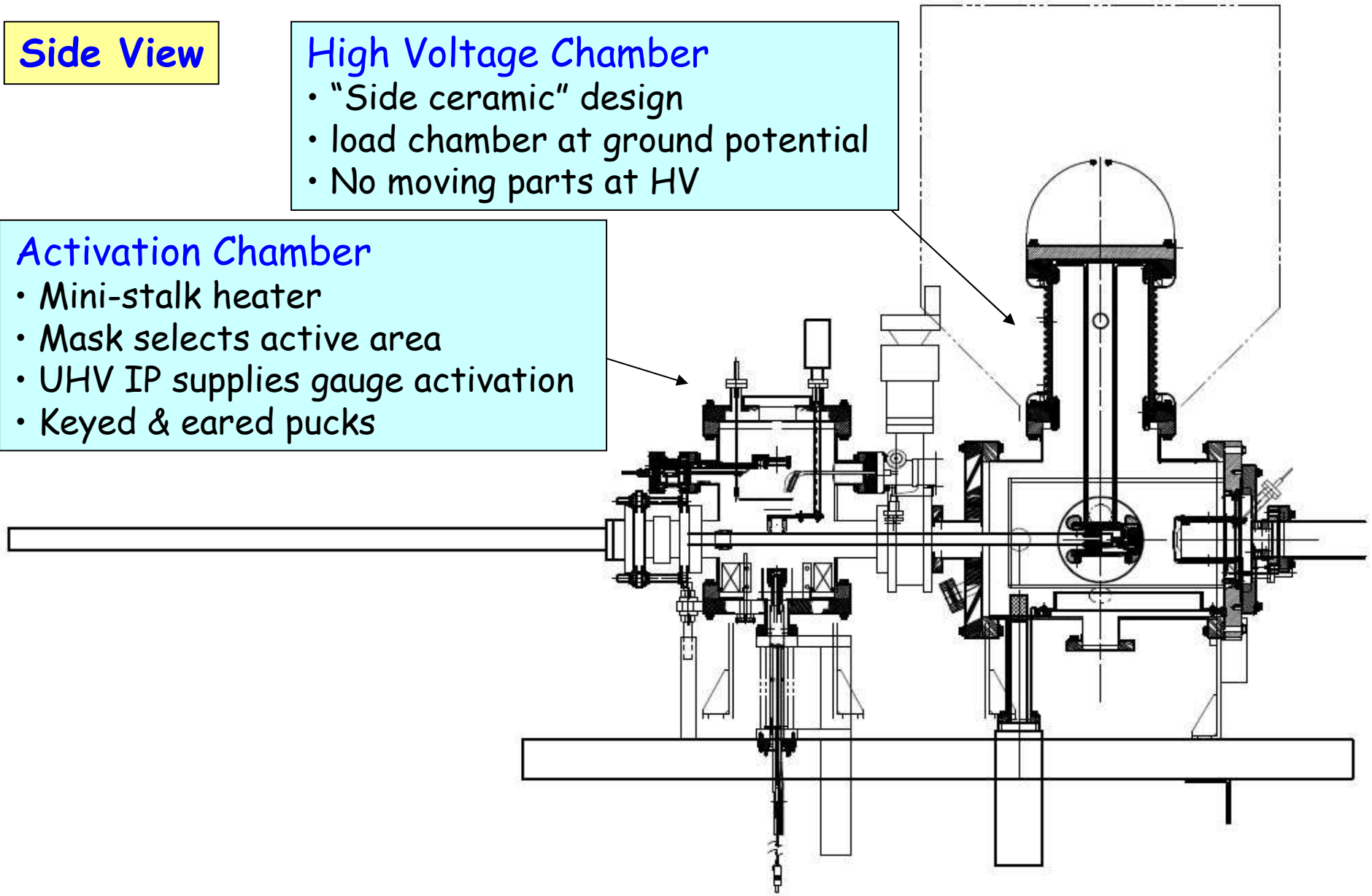
Side View

High Voltage Chamber

- "Side ceramic" design
- load chamber at ground potential
- No moving parts at HV

Activation Chamber

- Mini-stalk heater
- Mask selects active area
- UHV IP supplies gauge activation
- Keyed & eared pucks



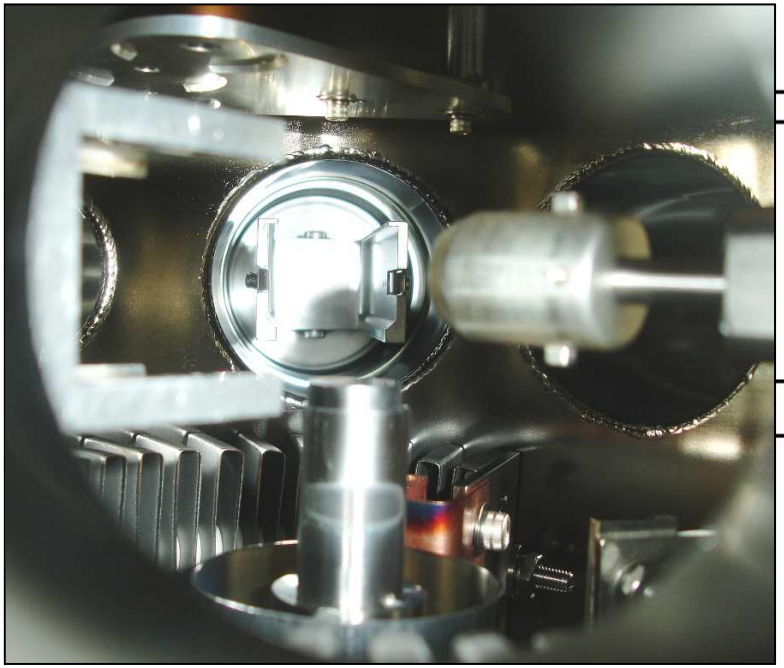
Side View

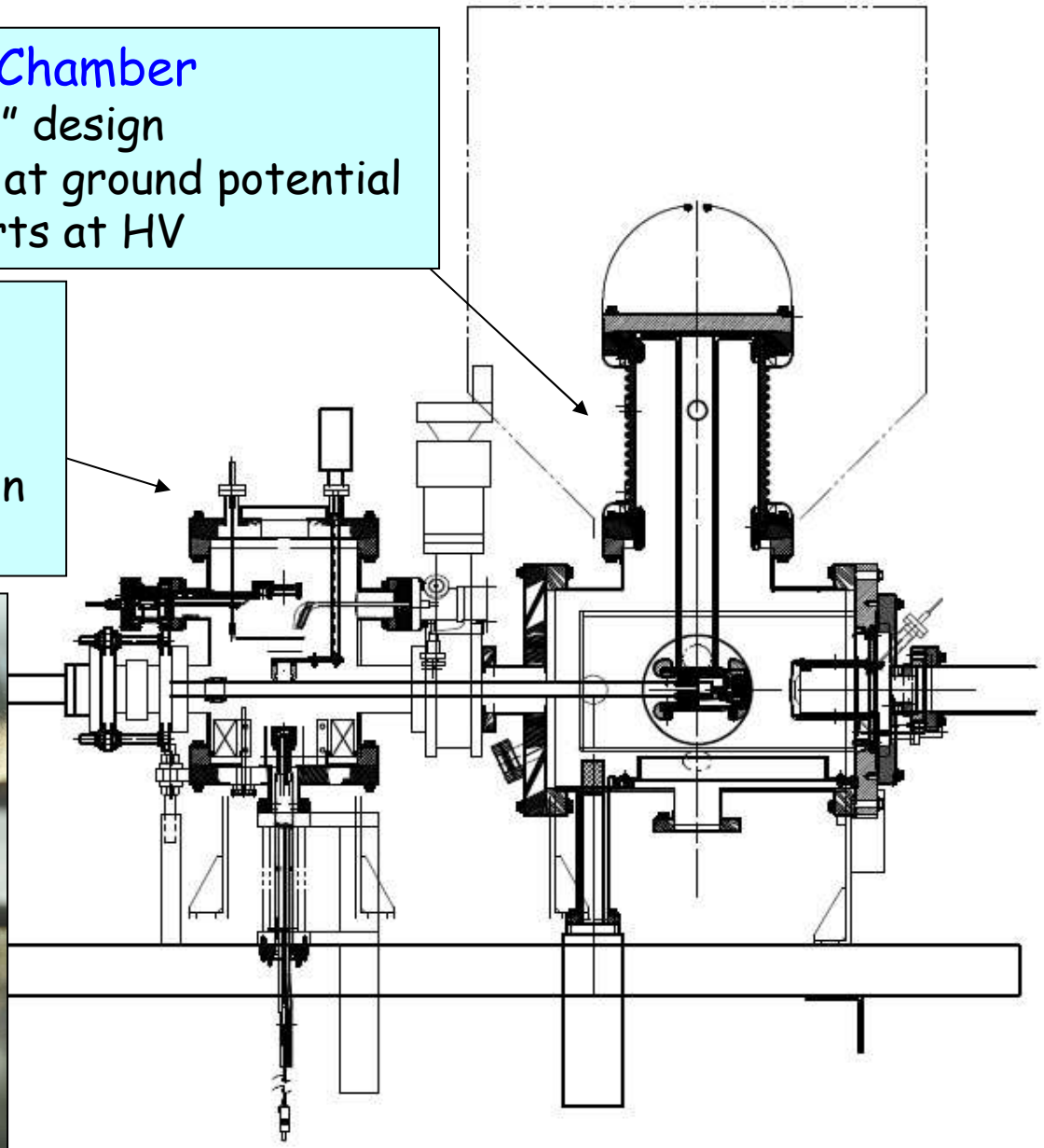
High Voltage Chamber

- "Side ceramic" design
- load chamber at ground potential
- No moving parts at HV

Activation Chamber

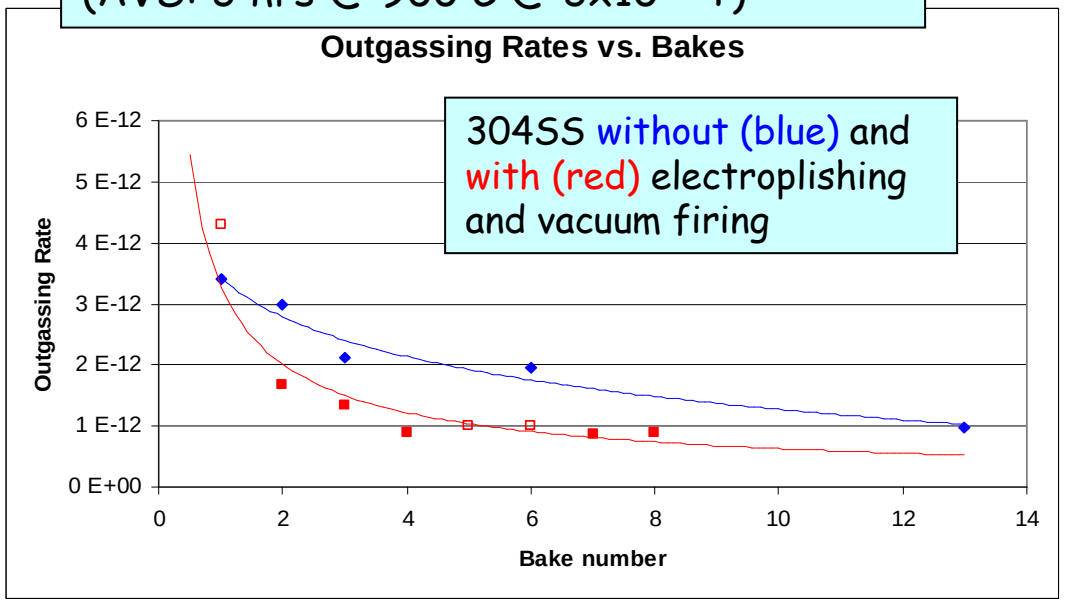
- Mini-stalk heater
- Mask selects active area
- UHV IP supplies gauge activation
- Keyed & eared pucks



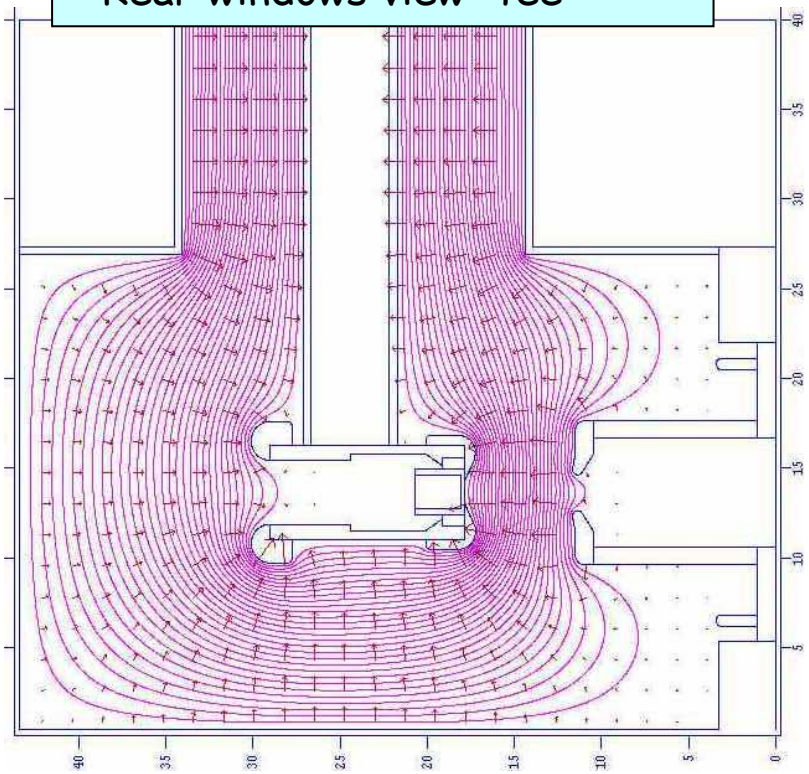


Improvements to the High Voltage Chamber

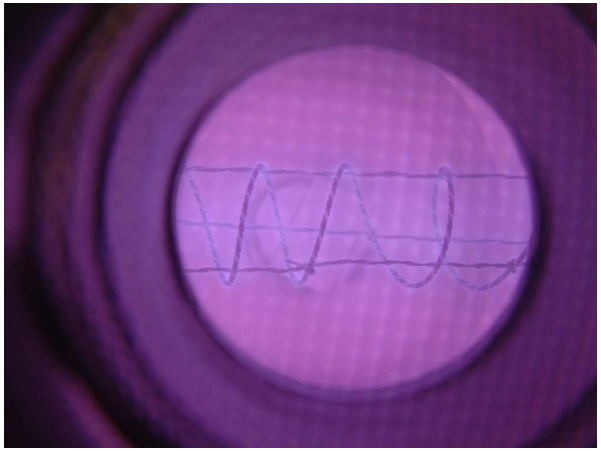
304 SS: Electropolished & Vacuum Fired
(AVS: 3 hrs @ 900 C @ $3x10^{-6}$ T)



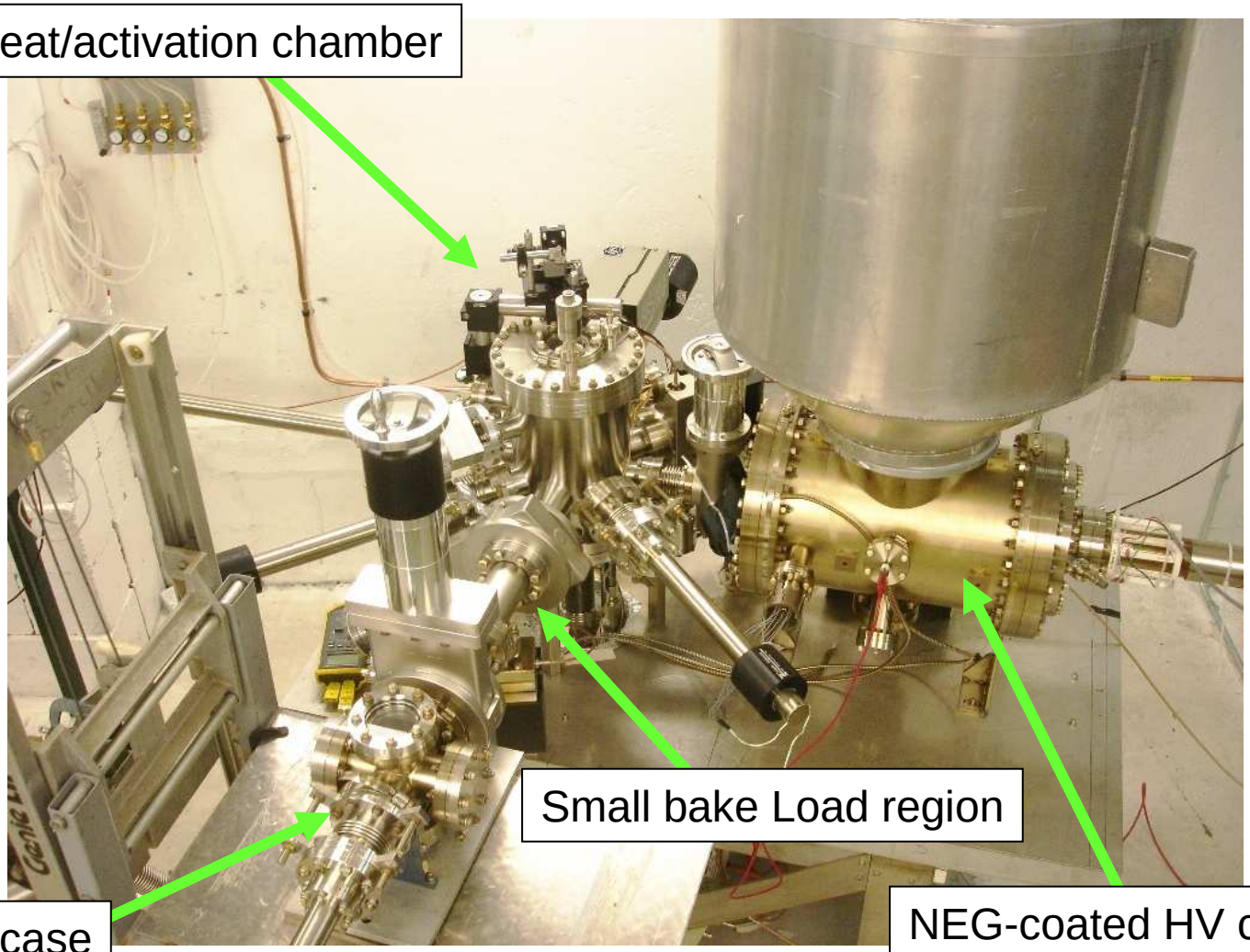
- Careful electrode alignment
- Lipped to flatten field profile
- Bias anode or support
- Rear windows view "tee"



NEG coating
(Ti/Zr/V)
100 hrs @ 70 C
200 L/sec



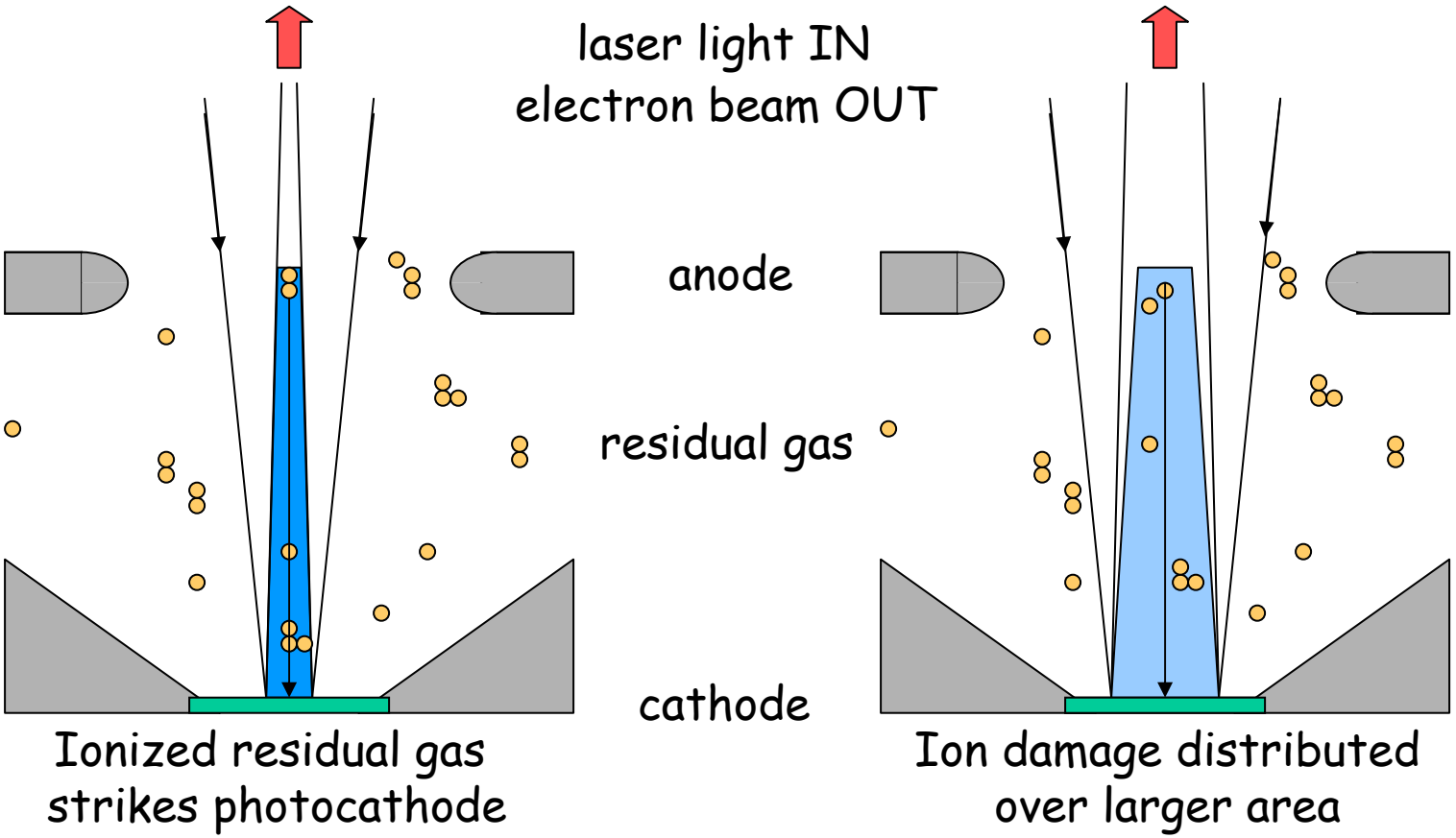
New Load Lock Gun Assembled & Running Spring '06



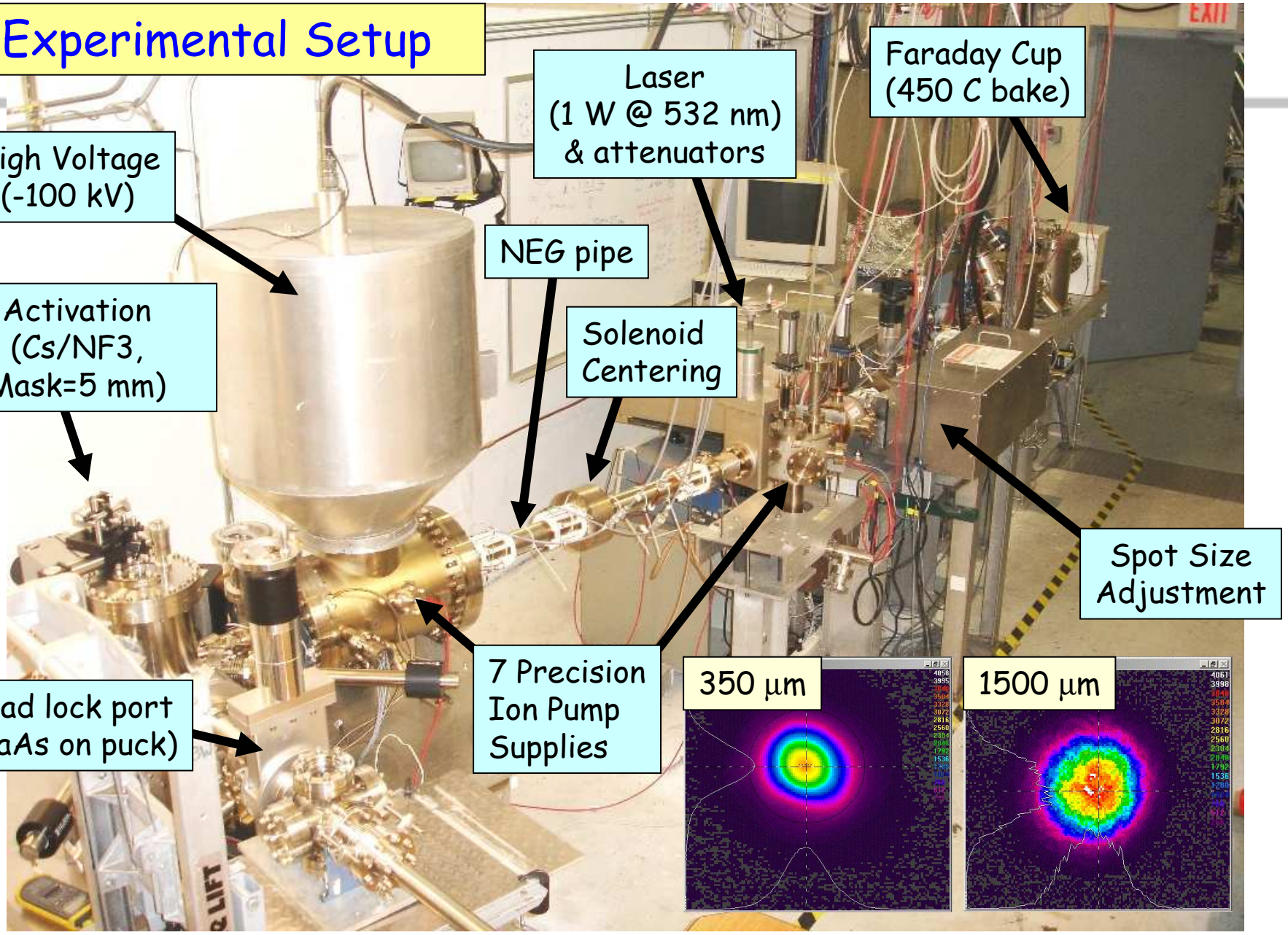
Benchmarking Photogun with Operational Lifetime

(Best Solution – Improve Vacuum, but this is not easy)

Bigger laser spot, same # electrons, same # ions



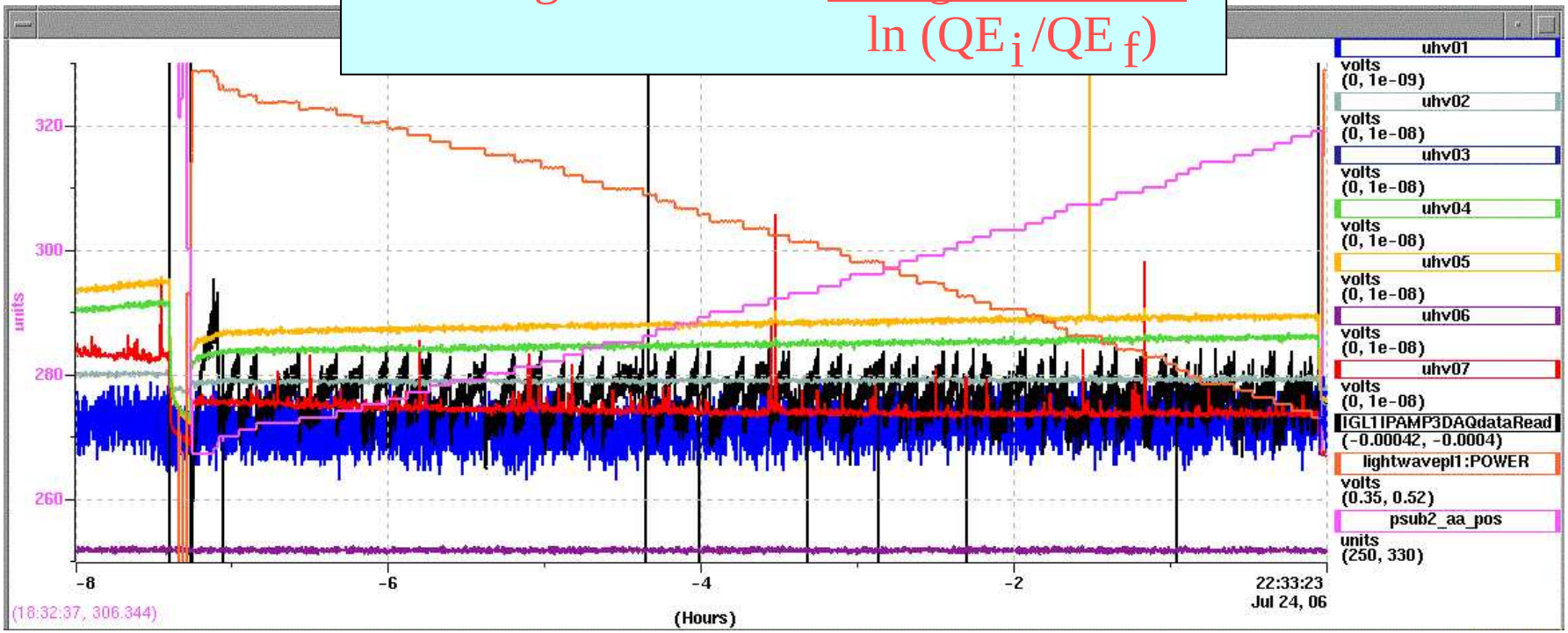
Experimental Setup



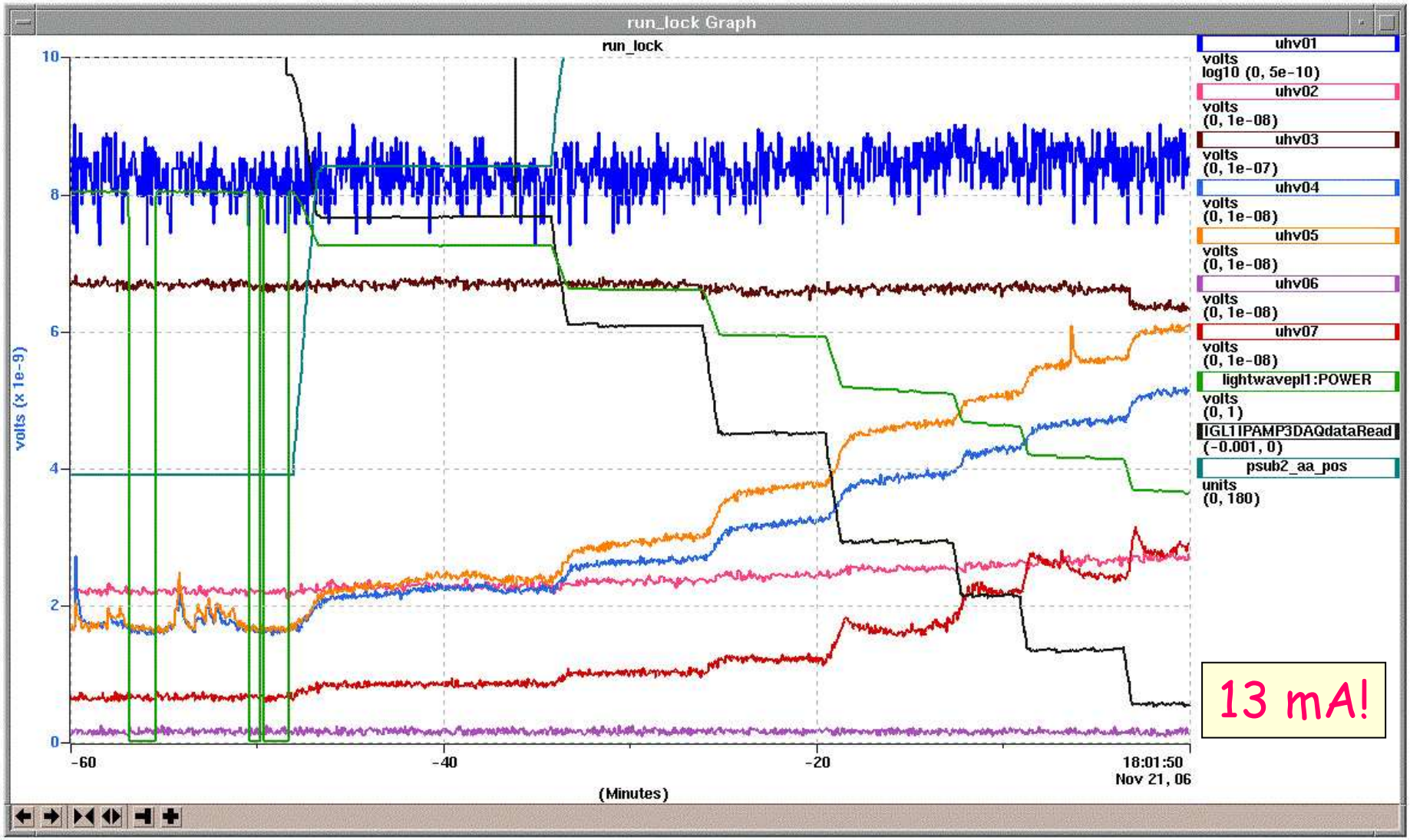
Example Run (5 mA)

- Run laser power (<1 Watt) PID to fix beam current
- Record ion pump current at 7 beam line locations
- Record laser power/setpoint via "pickoff" detector

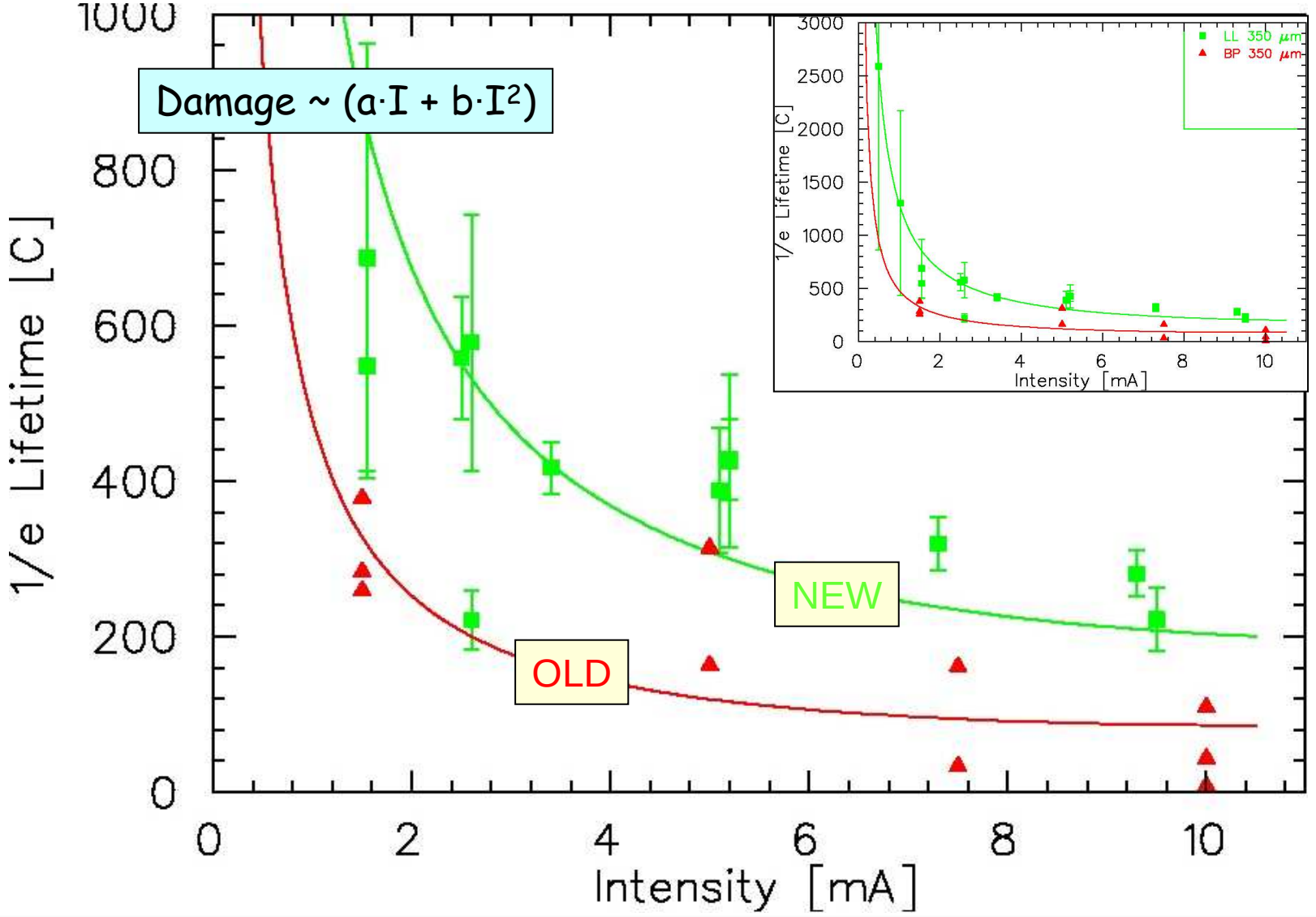
$$1/e \text{ Charge Lifetime} = \frac{\text{Charge Extracted}}{\ln (QE_i / QE_f)}$$



Measurements Limited by HV Power Supply

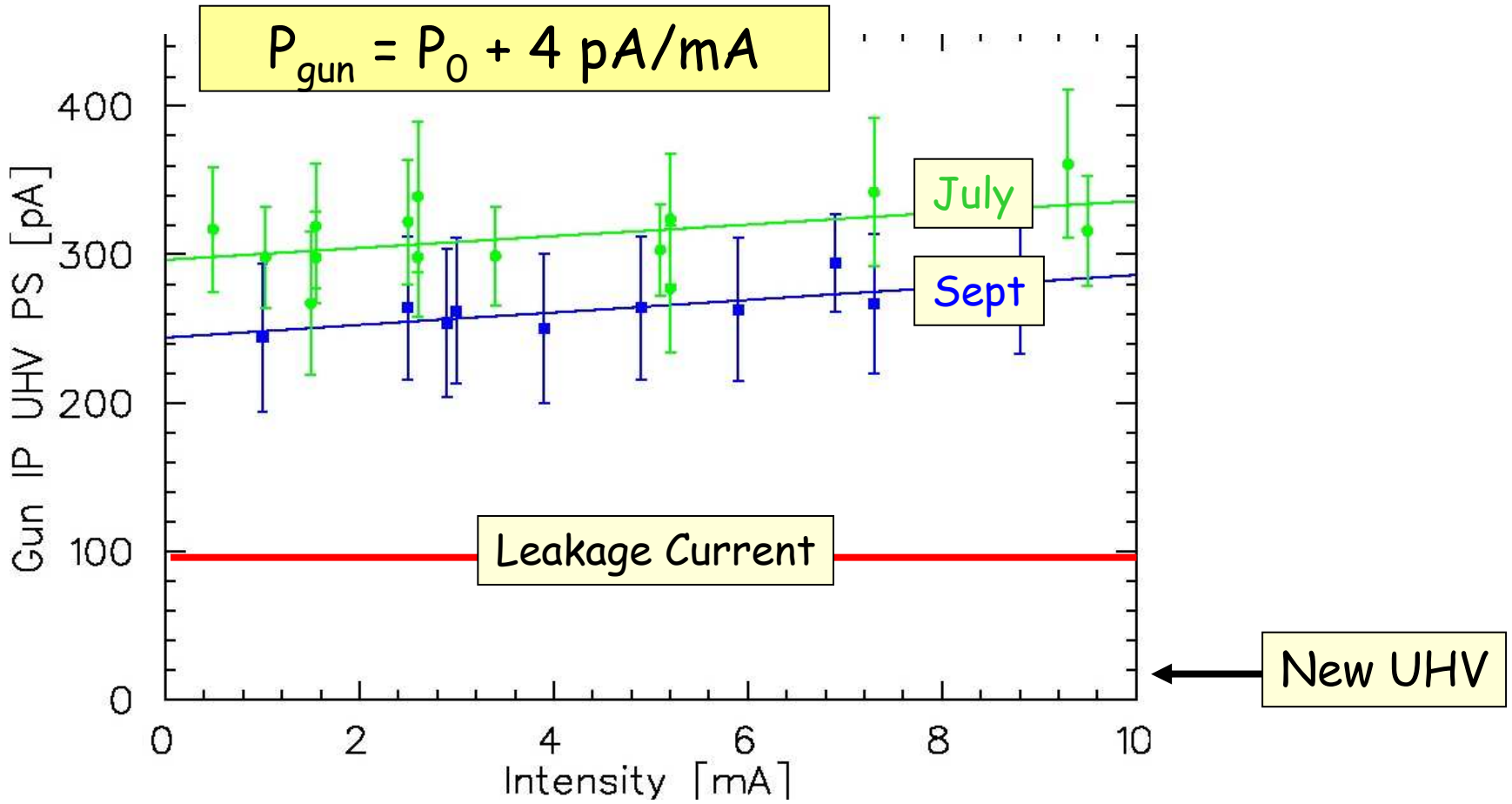


NEW vs. OLD Load Lock Design (small laser spot)

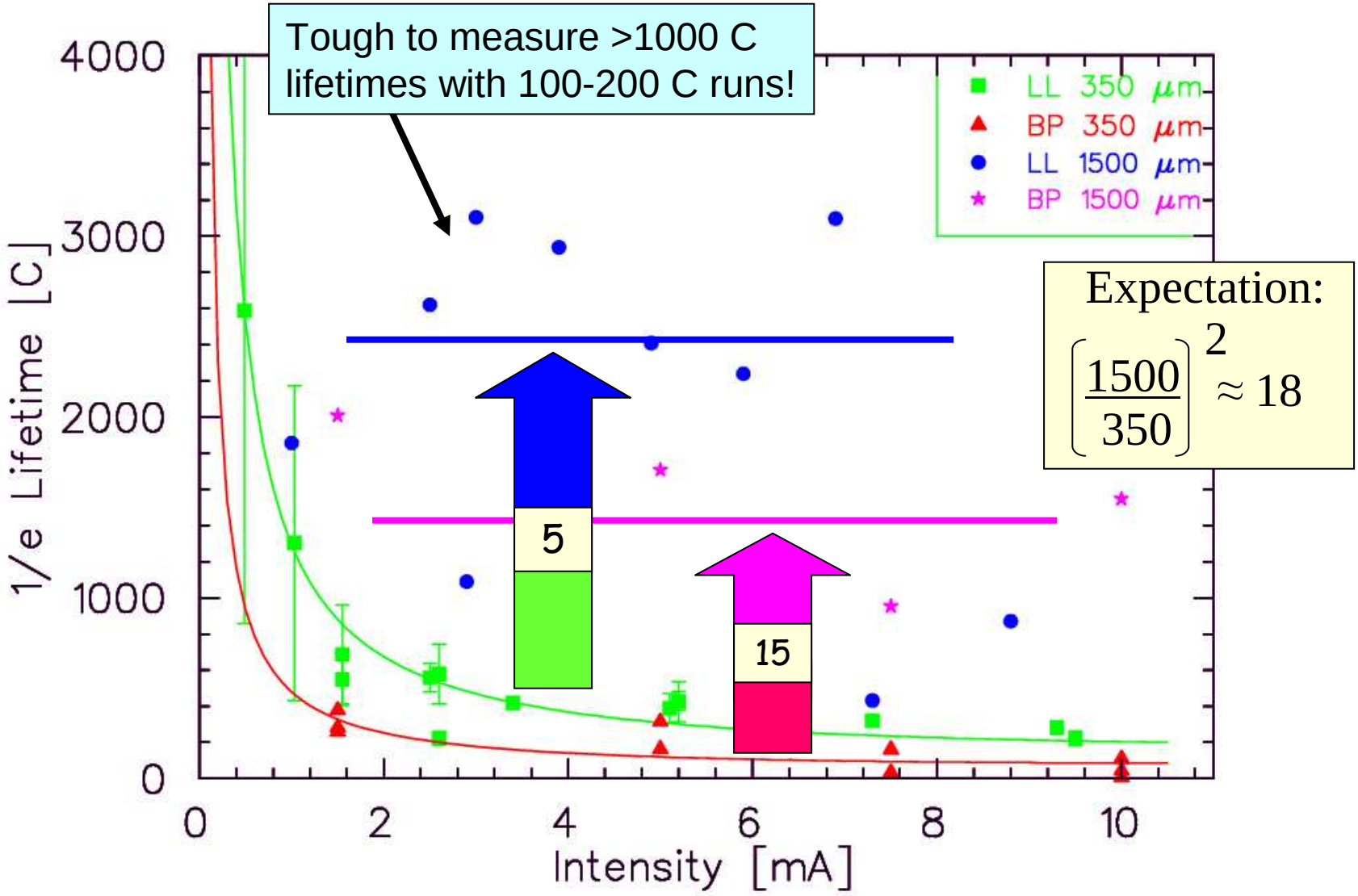


HV Chamber Pressure vs. Beam Intensity

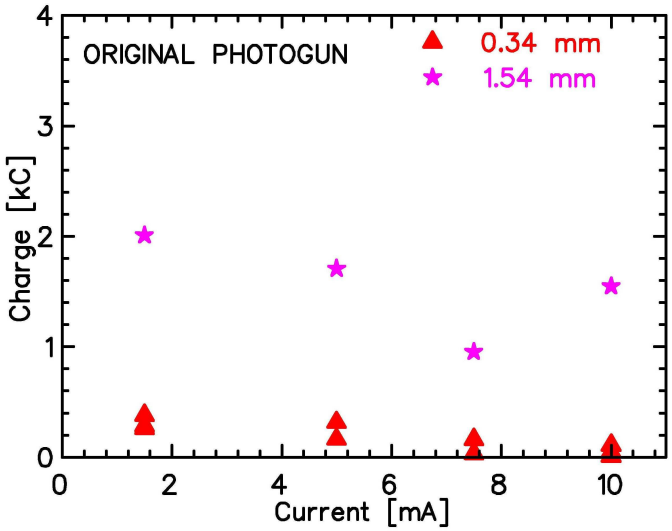
Gun Ion Production ~ Beam Intensity x Gun Pressure ~ $(a \cdot I + b \cdot I^2)$

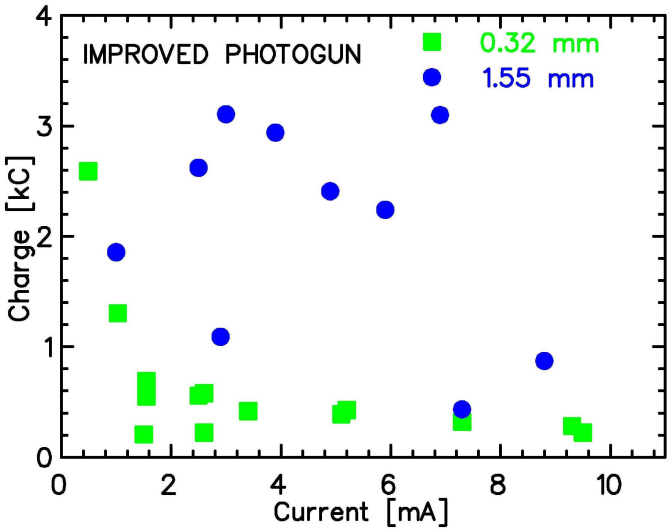


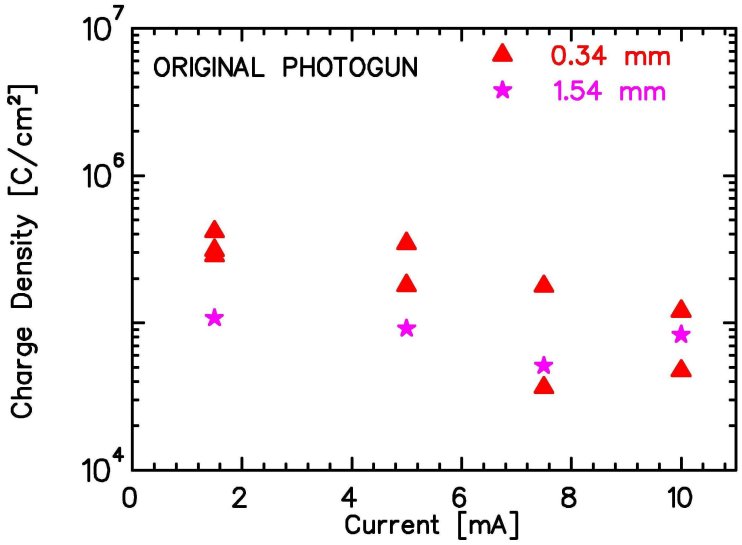
SMALL vs. LARGE Laser Spot (BP vs. LL)

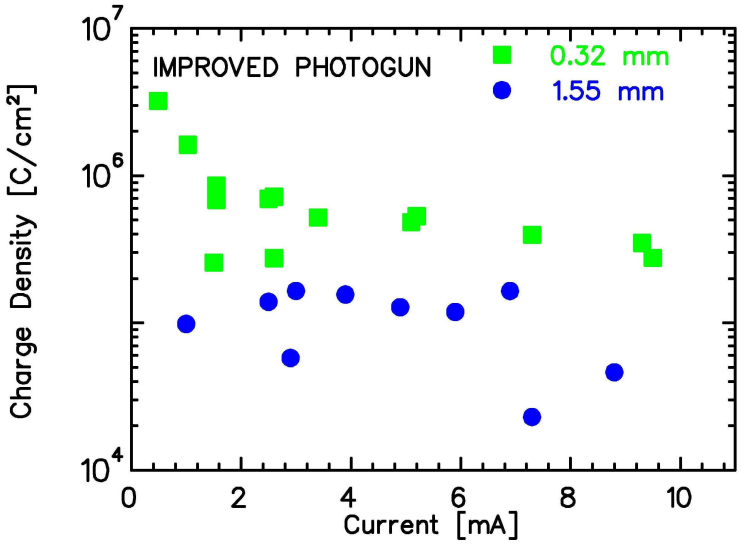


Side-by-Side Comparison of Original/Improved Guns

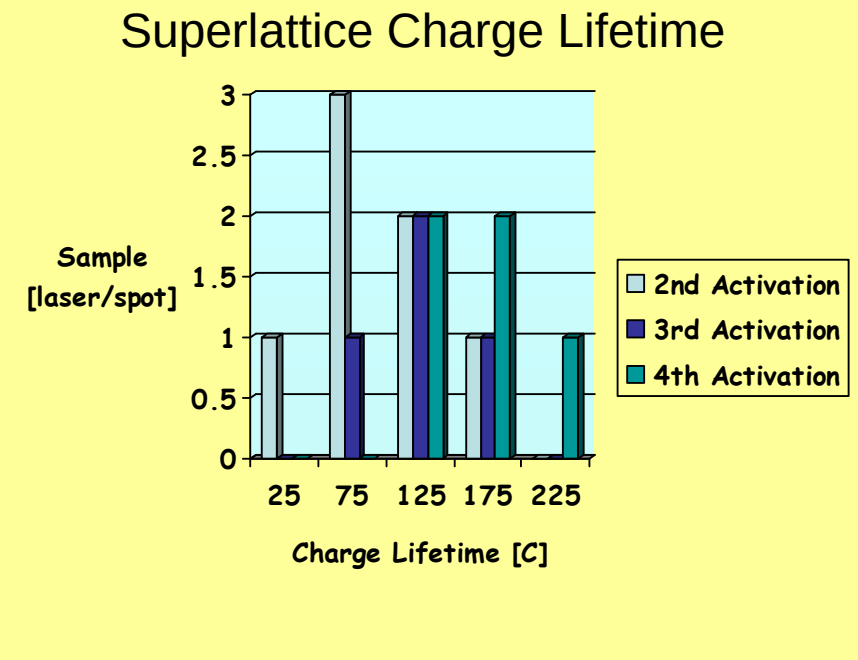


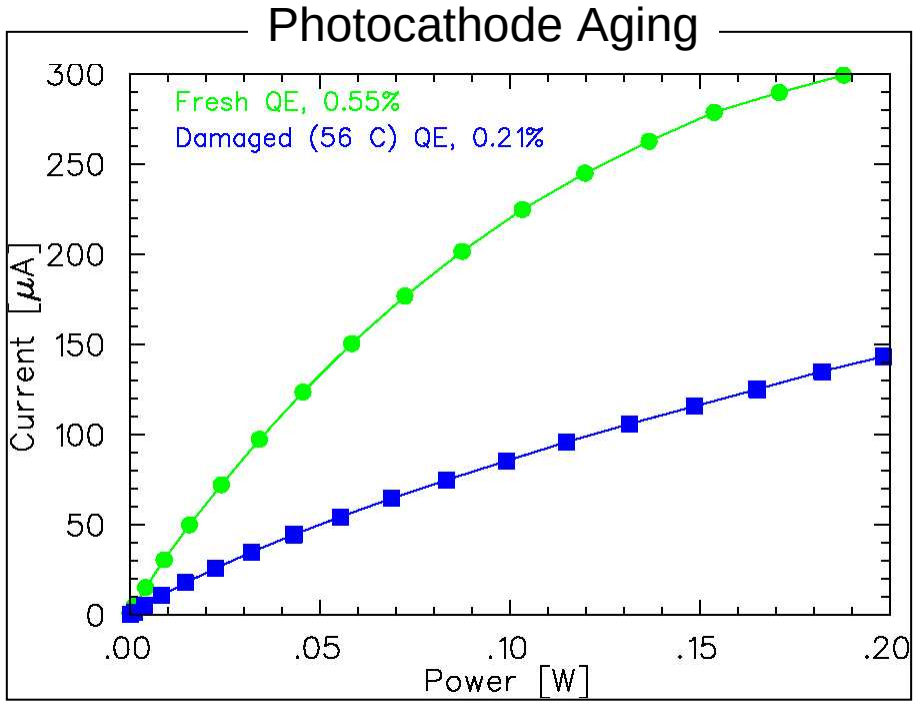






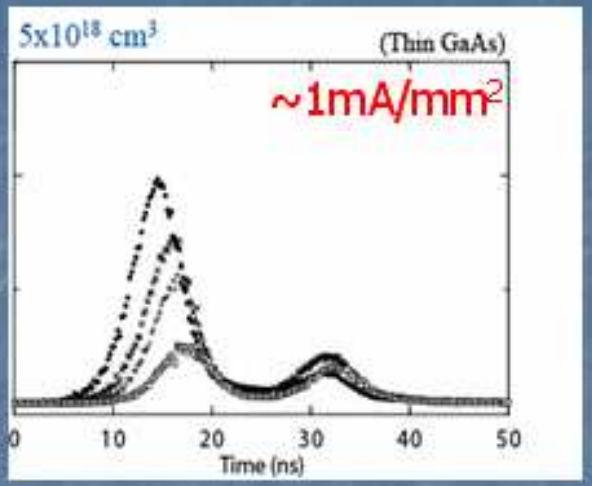
The "100 μA" 85% Photocathode

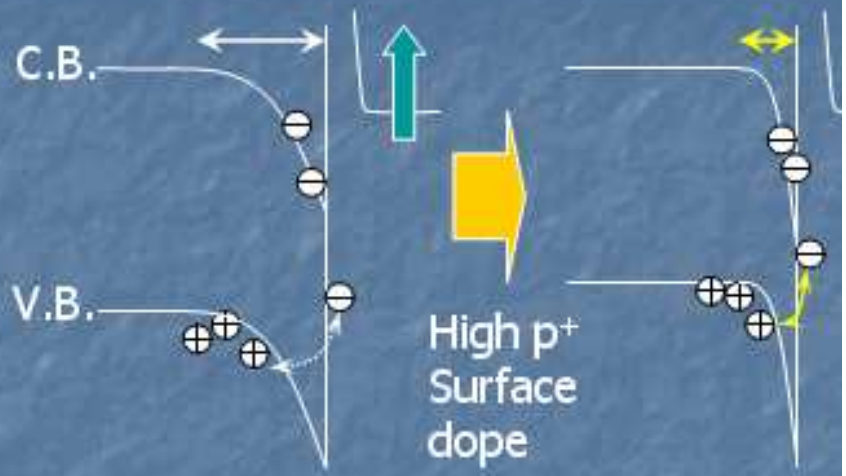


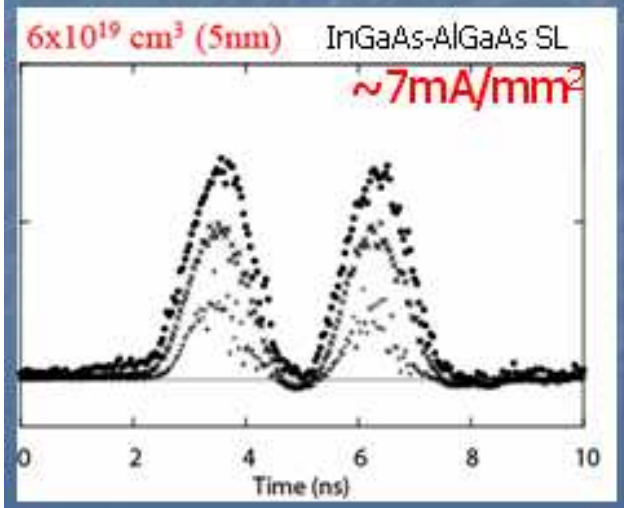


- We have no operational experience operating with superlattice at > 100 μA.
- Surface charge limit. QE droops at higher laser power. Old wafers get tired, must be replaced.

High Surface Charge Density Superlattice Photocathodes
(M. Yamamoto, Nagoya University)







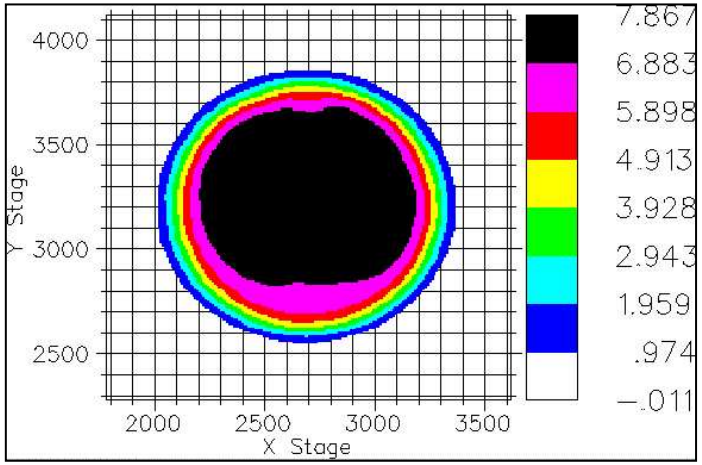
K.Togawa (2000) NIM-A 445 p118-122

<u>Superlattice photocathode</u>:

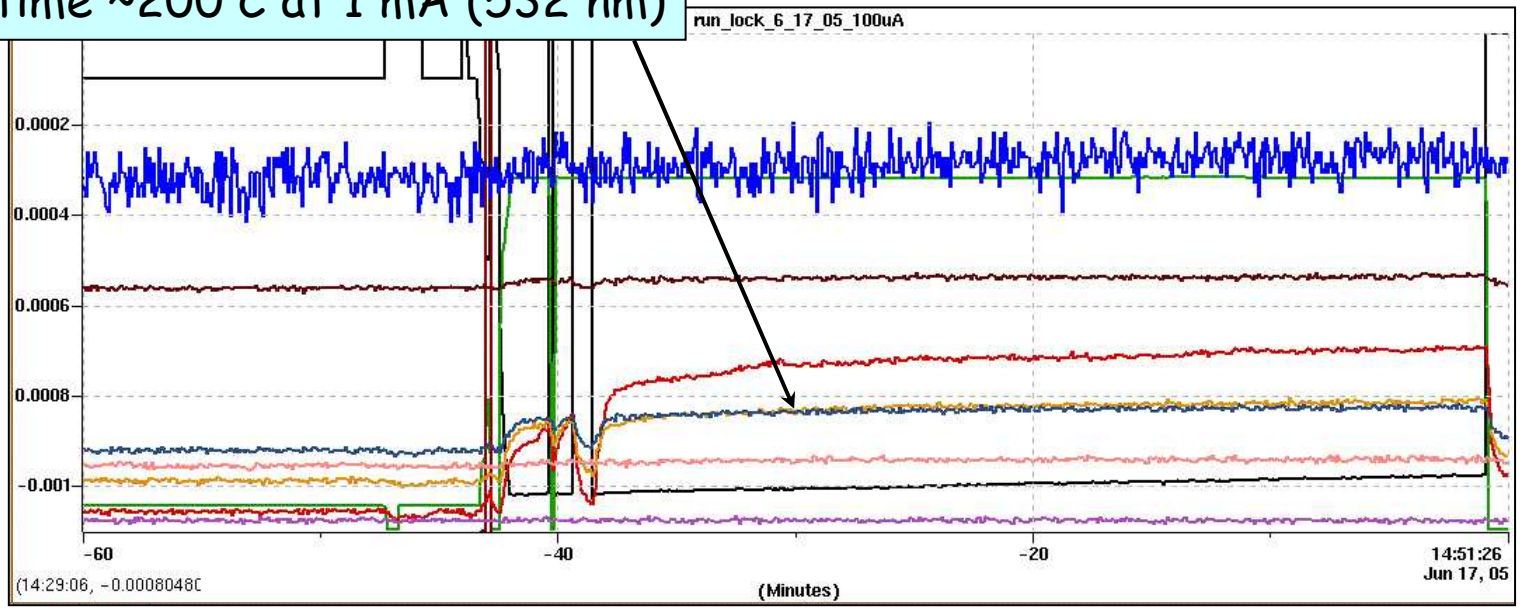
- Surface <100 nm is GaAs
- Similar doping, e.g., Zinc
- Concern: heat => diffuses dopant

Superlattice Test June '05: 1 mA @ 532

Brief opportunity to test superlattice photocathode with 532 nm DC laser in the original load lock gun



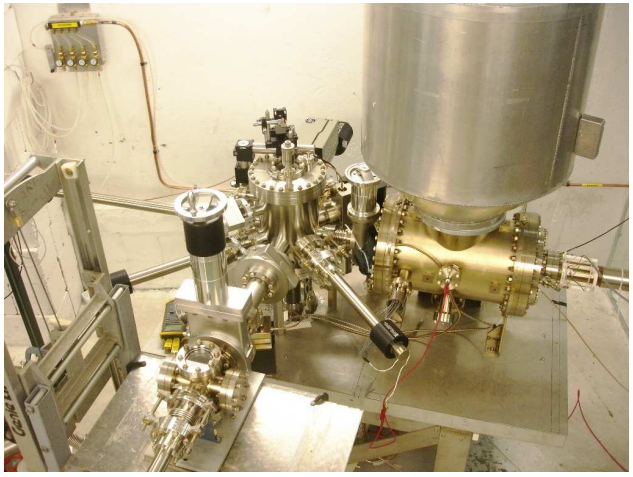
Lifetime ~200 C at 1 mA (532 nm)



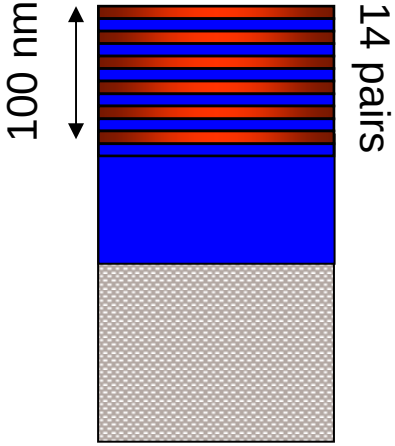
Now: High Current & High Polarization

Ingredients: Good gun, good photocathode, powerful laser

NEW Load Lock Gun

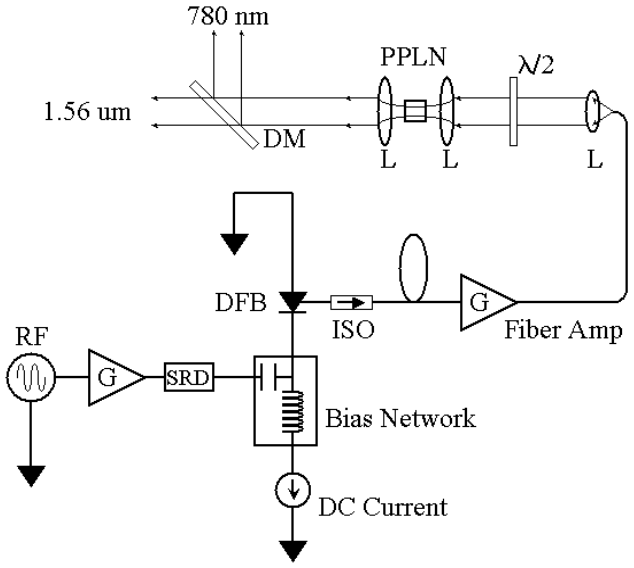


Superlattice GaAs: Layers of GaAs on GaAsP



No strain relaxation
QE ~ 0.6%
Pol ~ 85%
@ 780 nm

Fiber-based Laser

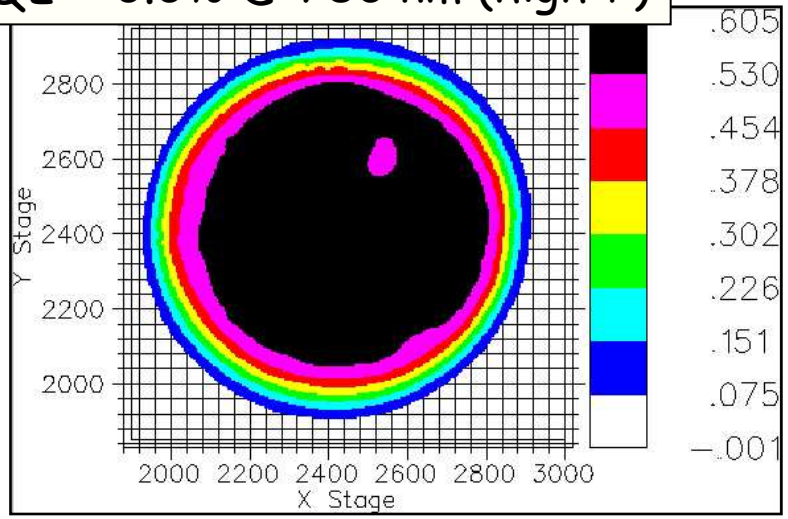


(Was: Ti:Sap)

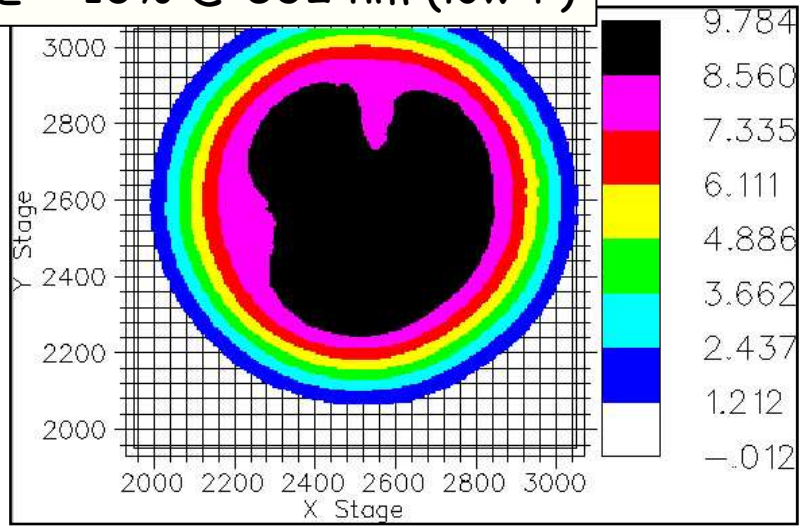
Superlattice in LL Gun

Successful activation

QE ~ 0.6% @ 780 nm (high-P)



QE ~ 10% @ 532 nm (low-P)



We have, so far, only measured *poor* photocathode lifetime (10's of C) at low average current (100 μA).

We have just begun…

…to measure how our experience with bulk translates to superlattice:

Bulk (robust)	?	Superlattice (fragile)
Band-deep light (532 nm)		Band-gap light (780 nm)
DC (peak=ave, no SC)		RF (ps & MHz)

Cause & effect is not always obvious, so we will replace the sample, repeat the measurement, verify the baseline and … enhance our understanding of photocathode decay mechanisms.

Conclusions

=> NEW gun charge lifetime 2-3x better; likely vacuum, electrode improvements.

=> Larger laser spot improves charge lifetime, but not simple model prediction.

=> Exceptionally good Charge Lifetime >1000 C at high currents >1mA; in fact, difficult to measure when using large laser spot.

=> Photocathode lifetime measurements at higher (>1 mA) currents using GaAs/GaAsP superlattice, but so far *poor* lifetime.

=> Install load lock in tunnel in July 2007.